Exhibit G-1: Daniel Hellerstein et al., Agricultural Resources and Environmental Indicators, 2019, EIB-208 (May 2019), Part 1 of 2

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# Agricultural Resources and Environmental Indicators, 2019

Daniel Hellerstein, Dennis Vilorio, and Marc Ribaudo (editors)

United States Department of Agriculture

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## Abstract

***Agricultural Resources and Environmental Indicators, 2019***, describes trends in economic, resource, and environmental indicators in the agriculture sector. Agriculture is dynamic, changing in response to economic, technological, environmental, and policy factors. The indicators covered in this report provide assessments of important changes in U.S. agriculture—the industry's development, its environmental effects, and the implications for economic and environmental sustainability. The individual chapters track key natural, produced, and management resources that are used in or are affected by agricultural production, as well as structural changes in farm production and the economic conditions and policies that influence agricultural resource use and its environmental impacts. The chapters also direct interested readers to ERS research and data that provide more detailed description and analysis.

**Keywords**: agricultural productivity, agricultural pest management, farmland ownership, irrigated agriculture, nutrient management, agricultural research and development, water conservation, antibiotics, biotechnology, Conservation Reserve Program, CRP, conservation tillage, cover crops, cropland acreage, CRP general and continuous signup, digital information technologies, drought adaptations, drought risk, erosion, farmland tenure, farmland values, forage suitability index, forestland, glyphosate, herbicide resistance, livestock, manure, oil and gas rights, organic soil matter, pasture and range, pollinators, honey bees, precision agriculture, soil health, Total Factor Productivity, TFP, U.S. conservation programs, U.S. land uses, water quality impacts of agriculture, wetland acres, wetland conservation programs, Wetlands Reserve Program, WRP.

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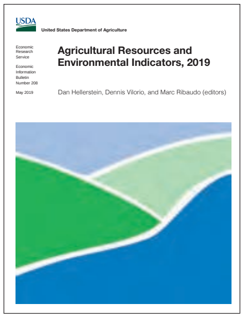
*A report summary from the Economic Research Service* *May 2019*




# Agricultural Resources and Environmental Indicators, 2019

Daniel Hellerstein, Dennis Vilorio, and Marc Ribaudo (editors)

## What Is the Issue?

Agricultural production affects a wide range of natural resources, including land, water, and air. This report provides concise information about how natural resources (land and water) and commercial inputs (energy, nutrients, pesticides, antibiotics, and other technologies) are used in the agricultural sector and how they contribute to environmental quality. To assist public and private decision making around how best to manage these resources and their impacts, the report further explores the complex links among public policies, economic conditions, farming and conservation practices, productivity and technological change, resource use, and the environment. The objective is to provide a comprehensive source of data and analysis on the factors that affect resource use and quality in American agriculture.

## What Did the Study Find?

*Notable findings for Farms and Farm Productivity include:*

- As of 2017, small farms (family farms with less than $350,000 in revenue) made up 89 percent of U.S. farms. But the 3 percent of farms with at least $1,000,000 in revenue accounted for 39 percent of production.
- In 2012, almost 53 percent of the 2.3 billion acres of land in the United States was used for agricultural purposes, including cropping, grazing (in pasture, range, and forests), farmsteads, and farm roads.
- Between the early 2000s and 2015, average U.S. farm real estate value nearly doubled in inflation-adjusted terms. Since 2015, the value of cropland has declined by nearly 5 percent.
- In 2014, 61 percent of land in farms was owner-operated, with the remaining land rented out by the landowner to a tenant farm operator. Non-operator landlords own 80 percent of all rented farmland.
- From 1948 to 2015, agricultural output grew 1.48 percent per year while aggregate input use increased only 0.1 percent annually on average.
- Since the early 2000s, private-sector food and agricultural research and development (R&D) has grown much more rapidly than public-sector R&D, so by 2014 the private sector spent nearly three times as much as the public sector.
- Corn, cotton, and soybean growers have widely adopted genetically engineered (GE) herbicide-tolerant (HT) and insect-resistant (Bt) seeds since 1996. By 2018, 90 percent of corn, cotton, and soybean acres planted in the United States used HT seeds, and 80 percent of corn and cotton acres used seeds also containing Bt traits.

ERS is a primary source of economic research and analysis from the U.S. Department of Agriculture, providing timely information on economic and policy issues related to agriculture, food, the environment, and rural America.

- Herbicide application rates per planted acre in 2014 compared to 2010 were up 21 percent for corn, 25 percent for cotton, 26 percent for wheat, and 24 percent for soybeans. The types of herbicides used have changed over time.
- Commercial fertilizer consumption was about 22 million short tons in 2015. For corn, winter wheat, and cotton, nitrogen recovery rates hovered around 70 percent, while phosphate recovery rates were at 60 percent.
- In 2012, irrigated farms represented about 14 percent of all U.S. farms but accounted for 39 percent of U.S. farm sales. Between 1984 and 2013, acreage in water-efficient sprinkler and drip/trickle systems rose from 37 to 76 percent of irrigated area in the Western United States.
- Precision agriculture comprises technologies such as guidance systems and variable-rate technology (VRT). By 2013, over 20 percent of planted corn, soybeans, and rice acreage were farmed using VRT.
- By the end of 2017, 44 percent of U.S. broiler chickens were raised without any antibiotics. Between 2004 and 2015, the share of finishing hogs from operations reporting that they *did not know* or *did not report* whether antibiotics were used for growth promotion rose from 7 percent to 35 percent.
- Conservation tillage, which can reduce soil erosion and sediment loss, is used on around 70 percent of soybean acres, 40 percent of cotton, 65 percent of corn, and 67 percent of wheat.
- U.S. organic retail sales reached an estimated $49 billion in 2017. The number of certified organic operations in the United States more than doubled between 2006 and 2016.
- Animal manure provides a source of nutrients for crops. In 2011, around 66 percent of broiler operations had a nutrient management plan, compared to 54 percent of hog operations and 41 percent of dairies.
- As of 2017, across the Nation, 55 percent of assessed rivers and streams; 71 percent of lakes; and 84 percent of bays and estuaries nationally have impaired water quality. Agriculture is the largest source of impairments in rivers and streams and the second-largest source in lakes and ponds.
- Drought is the leading cause of production risk and crop insurance indemnity payments in the United States. Practices such as irrigation adoption can reduce drought vulnerability.
- Many farmers and ranchers use practices that enhance soil health. In 2012, 35 percent of all cropland acres were in no-till and 3 percent were planted with a cover crop, two practices that promote soil health.
- Based on a land use-based measure of quality, pollinator forage habitat increased between 1982 and 2002, then declined until 2012. The decline was greatest in the Northern Plains, a summering ground for commercial beehives.
- Between 2007 and 2012, the number of farms producing energy or electricity onfarm with solar panels, geothermal exchange, wind turbines, small hydro, or methane digesters increased from 1.1 to 2.7 percent.
- Federal funding for the five largest voluntary programs that encourage land retirement and adoption of conservation practices on working lands was roughly $6 billion in 2017. In real (inflation-adjusted) terms, conservation spending increased in the 2002 and 2008 Farm Acts and declined in the 2014 Farm Act.
- Since 1992, freshwater wetlands in the contiguous United States have held steady at around 111 million acres.
- Between 2012 and 2018, acreage enrolled in USDA's Conservation Reserve Program (CRP) declined from 29.5 million to 22.4 million acres. However, land enrolled in the continuous portion of the CRP increased from 5.3 million to 8.1 million acres.
- In 2016, an estimated 1.7 percent of farms were enrolled in the USDA's Environmental Quality Incentives Program (EQIP), and 5.1 percent were enrolled in the Conservation Stewardship Program (CSP).

## How Was the Study Conducted?

Each chapter reflects the most recent data and information available on that topic as of July 2018. As described in the data appendix, the report relies heavily, but not exclusively, on the Agricultural Resource Management Survey (ARMS), the Census of Agriculture, and USDA Administrative data. This report was prepared before the release of the 2017 Census of Agriculture. Instead, the report uses the 2012 Census of Agriculture.

# Group 1: Farms and Farm Productivity

## Chapter 1.1—Farm Numbers and Size

Robert A. Hoppe and Christopher B. Burns

- Farm numbers appear to have stabilized since the 1970s, after sharp declines from 1938 through the early 1970s.
- As of 2017, small farms (family farms with less than $350,000 in revenue) made up 89 percent of U.S. farms. But the 3 percent of farms with at least $1,000,000 in revenue accounted for 39 percent of production.
- Farm programs generally target production, directly or indirectly. However, most of the payments for USDA's Conservation Reserve Program, which removes environmentally sensitive land from crop production, go to low-sales operations, such as retirement farms.

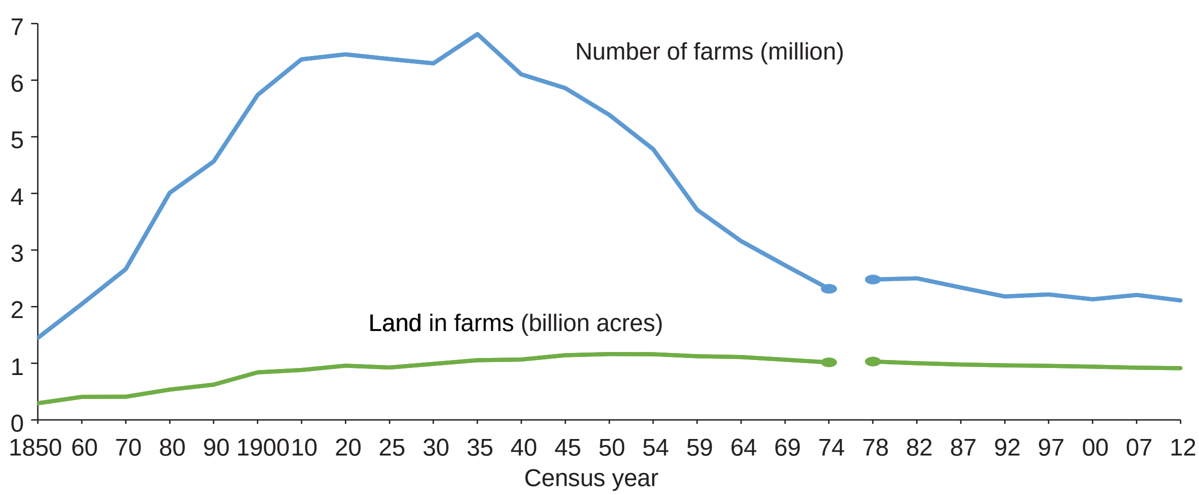
### Farm Numbers Stabilize

After peaking at 6.8 million farms in 1935, the number of U.S. farms fell sharply until the early 1970s (fig. 1.1.1). Falling farm numbers during this period reflect growing productivity that led to excess capacity in agriculture, farm consolidation, and the exit of farm operators to work in the nonfarm economy (see chapter 1.5, "Agricultural Productivity and Sources of Growth in the U.S. Farm Sector"). The decline in farm numbers slowed in the 1980s, and farm numbers stabilized in the 1990s, reflecting increases in the number of very small farms whose operators do not depend on farming for their livelihood. By 2012, there were about 2.1 million farms occupying 915 million acres of farmland, including cropland, pasture and rangeland, and woodland (see chapter 1.2, "Major Land Uses in the United States").

Figure 1.1.1

**Farms and land in farms, 1850-2012**

*Most of the decline in the farm count occurred between 1935 and 1974*




Note: The Census of Agriculture was conducted every 10 years from 1850 to 1920 and every 4 or 5 years starting in 1925. The break in the lines after 1974 reflects the introduction of an adjustment to estimates of the farm count and land in farms. Beginning in 1978, the data are adjusted to compensate for undercoverage by the Census of Agriculture. The adjustment was introduced in census publications in the 2002 Census of Agriculture, but was applied to selected estimates, including farms and land in farms, in appendixes to earlier censuses.
Source: USDA, Economic Research Service using data compiled from USDA, National Agricultural Statistics Service, Census of Agriculture.

Some of the increase in the number of very small farms that stabilized the farm count, however, occurred because of changes in how USDA's National Agricultural Statistics Service (NASS) conducts the Census of Agriculture. NASS now adjusts the farm count to account for undercoverage of small farms and has increased its efforts to contact all small farms for the Census. In addition, the $1,000 farm sales cutoff to qualify as a farm is not adjusted for inflation and has not changed since the current farm definition was adopted in 1974. This means that when commodity prices increase, the number of farms increases because less physical production is required to qualify as a farm. In other words, we do not know how much of the increase in small farms is due to measurement issues and how much is due to the actual entry of small farms.

While farm numbers appear to have stabilized, production has shifted to larger farms. Between 1991 and 2017, farms with gross revenue of $1 million or more (in 2017 dollars) increased their share of U.S. production from 30 percent to 39 percent. Today's farms are diverse, ranging from very small retirement and residential farms to large operations with gross revenue in the millions of dollars. It is important to differentiate between small farms that dominate the farm count and larger farms that dominate production totals.

## Farm Diversity—Classifying Small and Large Farms

One way to view the diversity of farms is to categorize them into more homogeneous groups. A farm classification developed by USDA's Economic Research Service focuses on family farms, where the majority of the business is owned by the principal operator—the person most responsible for running the farm—and relatives of the principal farm operator. The classification identifies four types of small family farms (annual revenue less than $350,000): retirement, off-farm occupation, farming-occupation/low-sales, and farming-occupation/moderate-sales (see box, "Farm Types").

Small farms dominate the farm count, making up 89 percent of all U.S. farms in 2017 (table 1.1.1). Production, however, is concentrated among the remaining groups: midsize, large, and very large family farms, as well as nonfamily farms. Together, these classes accounted for 74 percent of the value of agricultural production in 2017. Large-scale family farms (annual gross revenue above $1 million) alone accounted for 39 percent of U.S. farm production, while comprising only 3 percent of farms. Large-scale farms account for much larger shares of agricultural production than their share of farmland. This is largely due to their commodity mix: large-scale farms include many fruit and vegetable operations, cattle feedlots, and dairy farms, which generate high values of production on limited land bases.

## Farm Types

The farm classification developed by the Economic Research Service (ERS) focuses on the "family farm," or any farm where the majority of the business is owned by the principal operator—the person most responsible for operating the farm—and individuals related to the principal operator, including relatives who do not live in the operator's household. Farm size in the classification is measured by the farm's gross revenue, the sum of crop and livestock sales, Government payments, and other farm-related income, including fees from production contracts. The USDA defines a farm as any place that produced and sold—or normally would have produced and sold—at least $1,000 of agricultural products during a given year.

### Small family farms (Gross revenue less than $350,000)

**Retirement farms.** Small farms whose principal operators report they are retired, although they continue to farm on a small scale.

**Off-farm occupation farms.** Small farms whose principal operators report a primary occupation other than farming.

**Farming-occupation farms.** Small family farms whose principal operators report farming as their primary occupation.

- **Low sales.** Gross revenue less than $150,000.
- **Moderate sales.** Gross revenue between $150,000 and $349,999.

### Midsize family farms

**Midsize family farms.** Farms with gross revenue between $350,000 and $999,999.

### Large-scale family farms
(Gross revenue of $1,000,000 or more)

**Large farms.** Farms with gross revenue between $1,000,000 and $4,999,999.

**Very large farms.** Farms with gross revenue of $5,000,000

### Nonfamily farms

**Nonfamily farms.** Any farm where the operator and persons related to the operator do not own a majority of the business.

Table 1.1.1

**Distribution of farms, production, farmland, and Government payments by type of farm, 2017**

| Type of farm | Farms | Value of production | Acres of farmland operated[1] | Commod-ity-related programs[2] | Conser-vation Reserve Program[3] | Working land programs[4] | Total payments[5] |
|---|---|---|---|---|---|---|---|
| Small family farms | | | | | | | |
| Retirement | 10.7 | 1.3 | 3.9 | 1.7 | 21.6 | 1.5 | 5.3 |
| Off-farm occupation | 40.8 | 4.9 | 17.1 | 5.9 | 28.6 | 10.5 | 10.9 |
| Farming-occupation | | | | | | | |
| Low-sales | 31.7 | 9.5 | 18.2 | 8.7 | 21.9 | 6.4 | 11.0 |
| Moderate-sales | 5.7 | 10.3 | 12.7 | 11.3 | 6.5 | 14.2 | 10.9 |
| Midsize family farms | 6.3 | 22.7 | 23.2 | 33.0 | 10.3 | 29.3 | 28.1 |
| Large-scale family farms | | | | | | | |
| Large farms | 2.5 | 23.1 | 15.9 | 30.5 | 5.4 | 29.9 | 25.7 |
| Very large farms | 0.3 | 15.6 | 2.4 | 3.8 | 0.4 | 4.0 | 3.2 |
| Nonfamily farms | 2.2 | 12.4 | 6.5 | 5.2 | 5.2 | 4.2 | 5.0 |
| All farms | 100 | 100 | 100 | 100 | 100 | 100 | 100 |

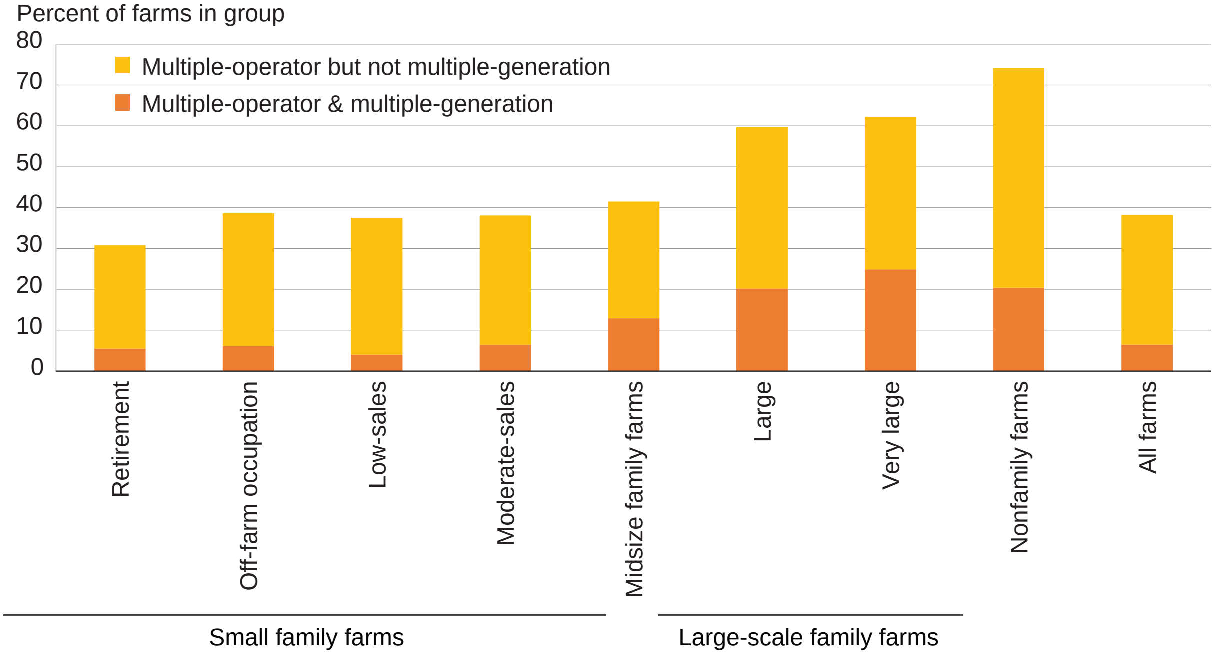
Source: USDA, Economic Research Service and USDA, National Agricultural Statistics Service, 2017 Agricultural Resource Management Survey.

## Multiple-Operator Farms

In addition to the principal operator, some farms may have additional, or secondary operators involved in running the farm business. There were 728,200 multiple-operator farms in 2016, representing 38 percent of all U.S. farms (figure 1.1.2).[1] Because farms are generally family businesses, most secondary operators are family members, particularly on smaller farms. On larger farms, secondary operators are more likely to come from outside the family, and often add specific management skills needed for the farm business.

[1]Numbers on multiple-operator and multiple-generation farms for 2017 are not displayed due to changes in the methodology for collecting data on operator demographics in the 2017 ARMS.

Figure 1.1.2
**Multiple-operator and multiple-generation farms by farm type, 2016**
***Multi-generation farms are most common among large-scale and nonfamily farms***




Source: USDA, Economic Research Service and USDA, National Agricultural Statistics Service, 2016 Agricultural Resource Management Survey.

Many large-scale farms are also multi-generation farms, with at least a 20-year age difference between the oldest and youngest operators. The presence or absence of younger related operators may affect farm expansion and contraction decisions, depending on the principal operator's lifecycle position. Principal and secondary operators on multiple-generation nonfamily farms, however, are likely to be unrelated managers from different generations.

## Government Programs by Type of Farm

The farm typology can also be used to examine how different farm programs affect different types of farms. Consider, for example, the distribution of commodity program payments. Receipt of these payments depends on past or current production of specific commodities covered by farm programs. Since moderate-sales small farms, midsize family farms, and large family farms harvest 79 percent of the land in program commodities (largely food and feed grains, oilseeds, and dry edible beans/peas/lentils), they receive a similar, 75-percent share of commodity program payments (see previous table). In contrast, very large family farms and nonfamily farms together receive only 9 percent of commodity program payments, equal to their 9-percent share of harvested land in program commodities. This pattern reflects differences in commodity mix across typology classes, with very large and nonfamily farms showing a substantial concentration on fruits, vegetables, and livestock that do not receive commodity program support.

Working-land programs provide technical and financial assistance to farmers using conservation practices on land in production (see chapter 3.24, "Working-Lands Programs"). The majority of working-land program payments go to midsize and large family farms, but small family farms also received more than a third of the payments. Like commodity-related programs, working-land programs target production, although indirectly, by focusing on lands in production. On the other hand, the Conservation Reserve

Program (CRP) targets environmentally sensitive land, not the production of commodities (see chapter 3.23, “Conservation Reserve Program: Status and Trends”). Retirement, off-farm occupation, and low-sales family farms together received 73 percent of CRP payments in 2017. Participating farmers in each of the three groups tend to enroll large shares of their land in these programs.

Because their main job is off-farm, off-farm occupation operators have limited time to spend farming. Off-farm occupation farmers may find CRP attractive because participating in the program requires little time. Given their advanced age, many retired farmers having environmentally sensitive land available may choose to participate in the CRP as they scale down their operations. The same forces may also be acting on low-sales operators, who average 62 years of age and may also be scaling down their operations.

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# Chapter 1.2—Major Land Uses in the United States

Daniel Bigelow

- As of 2012, grassland pasture and range (29 percent) and forest (28 percent) uses account for the largest shares of land in the United States.
- More than half of all land in the United States (53 percent) is used for some type of agricultural purpose, including crop production, grazing, farmsteads, and farm roads.
- Land use can vary substantially within regions—for example, 75 percent of Iowa is cropland versus just 41 percent of Ohio.

The U.S. land area totals nearly 2.3 billion acres. In 2012, grassland pasture and range uses accounted for the largest share of land use (29 percent of all land), followed by forest uses (28 percent) and cropland (17 percent). Just under 53 percent (1.18 billion acres) of U.S. land is used for some type of agricultural purpose, including crop production, grazing, farmsteads, and farm roads.[1]

## Land Use Varies by Region and Over Time

Since 1949, the first year of the most recent version of the ERS Major Land Uses (MLU) data series, areas of land in the top land-use categories have fluctuated.[2] For example, between 1949 and 1997, land used for grassland pasture and range decreased by 52 million acres (8 percent), but the land in this category has increased by 75 million acres (13 percent) since 1997 (figure 1.2.1). Total cropland declined by approximately 86 million acres (18 percent) between 1949 and 2012, but there were fluctuations within this interval due to Federal land retirement programs, market trends, and technological improvements. In contrast, the total acreage of urban land has exhibited a consistent upward trend over the past 60 years as cities expand to accommodate economic and population growth.

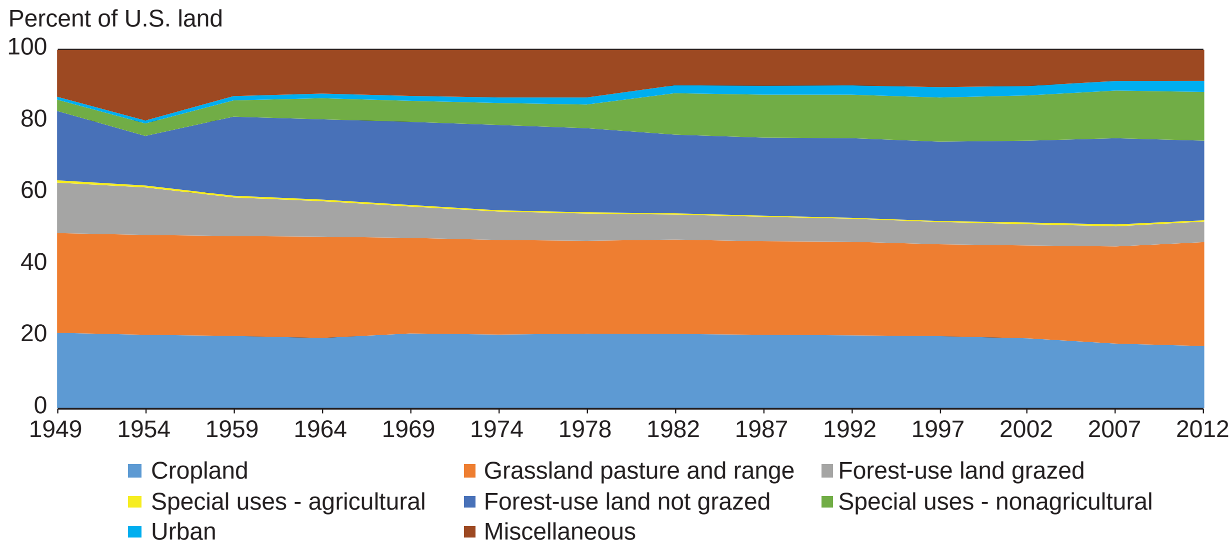
Regional land-use patterns vary based on differences in soil, climate, national and local policies and programs, topography, and population. For example, roughly 62 percent of land in the Southeast region is in forest use, compared to just 3 percent of land in the Northern Plains (figure 1.2.2). Similarly, land use varies between States within a given region. In Ohio, for instance, 41 percent of land is cropland, which contrasts with nearly 75 percent of Iowa. (State-level estimates and sources for all MLU categories are available in the ERS Major Land Uses data product.)

[1]In 2012, the Census of Agriculture reported that there were 914 million acres of farmland in the United States. The amount of land used for agricultural purposes reported in *Major Land Uses* is higher because the National Agricultural Statistics Service (USDA, NASS) definition of a farm for census purposes only covers land in operations that are capable of earning at least $1,000 in revenue in a given year and may not include all low-value land used for agricultural purposes, such as grazing.

[2]The Major Land Uses data series started in 1945, but did not include Alaska and Hawaii until 1949.

Figure 1.2.1

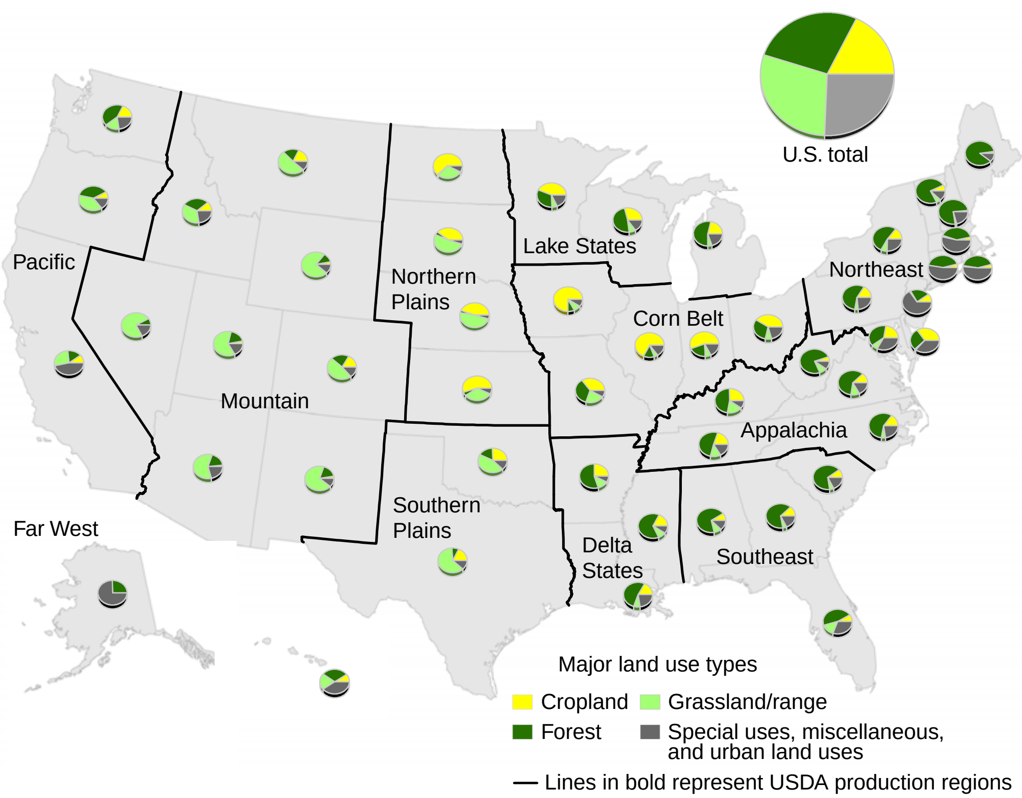
**Trends in major land use categories**




Source: USDA, Economic Research Service calculations drawing on data from U.S. Department of Agriculture, U.S. Department of the Interior, U.S. Department of Commerce, and other sources. Y-axis values represent the percent of census-reported U.S. land area (2.26 billion acres in 2010). See sources and reference list in Bigelow and Borchers (2017) for detailed source descriptions.

Figure 1.2.2

**State-level shares of major land uses, 2012**




Source: USDA, Economic Research Service calculations drawing on data from U.S. Department of Agriculture, U.S. Department of the Interior, U.S. Department of Commerce, and other sources. See sources and reference list in Bigelow and Borchers (2017) for detailed source descriptions.

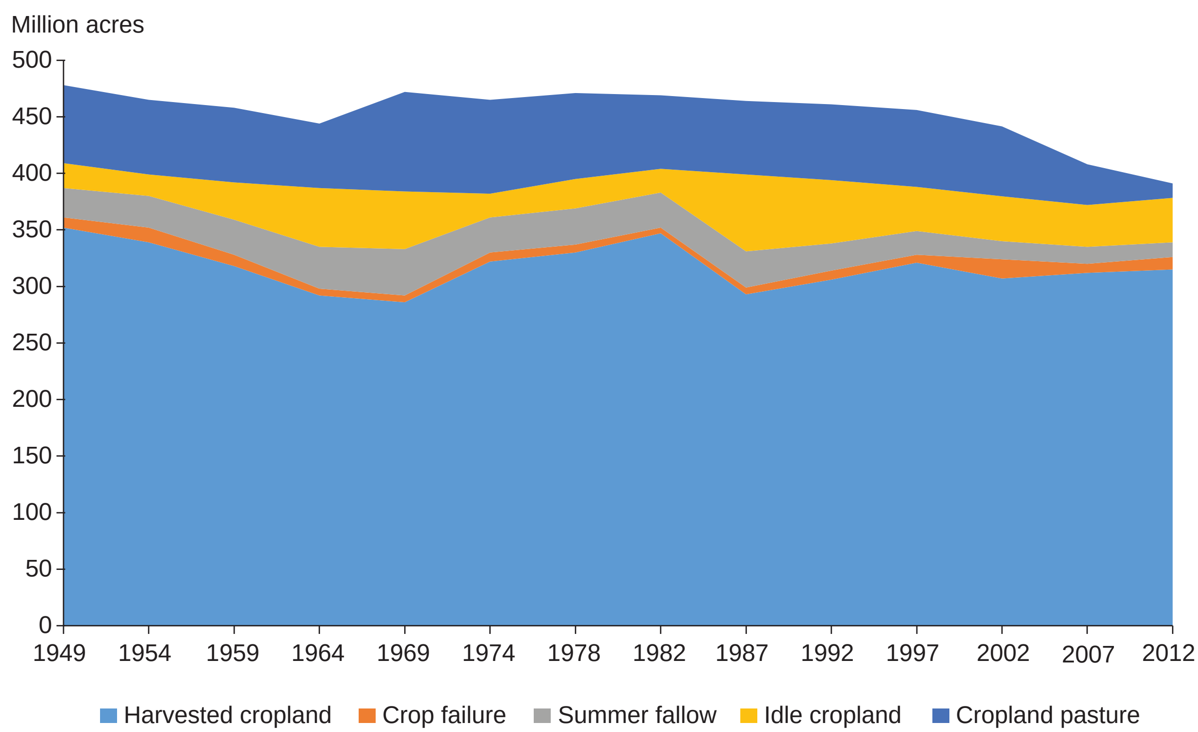
While land-use changes are not uncommon, most land remains in the same use from year to year. Between 2007 and 2012, according to the USDA, Natural Resource Conservation Service's (2014) National Resources Inventory, 97-99 percent of privately owned cropland (including land enrolled in USDA's Conservation Reserve Program (CRP)), pasture/range, urban land, and forest land did not change use. Over a longer period, 1982-2012, the rate of land-use change is larger, with 83, 86, and 91 percent of cropland/CRP land, pasture/range, and forest land, respectively, remaining in its 1982 use.

Where they occur, transitions between land uses take place for a variety of reasons. Changing commodity and timber prices, agricultural and natural resource policies, and environmental factors (such as droughts) can cause landowners to convert land from one use to another. Proximity to urban areas can also lead landowners to develop or sell their land for residential, commercial, or industrial purposes. However, in contrast to land-use changes between undeveloped uses (e.g., cropland to pasture, or vice versa), land development is generally irreversible. Once developed, land is rarely converted back to agricultural or forest-based uses.

In 2012, total cropland—which includes cropland used for crops, idled cropland, and cropland used for pasture—was 392 million acres, its lowest level since the MLU series began in 1945 (figure 1.2.3). This is largely attributable to a reclassification of cropland temporarily used for pasture to permanent grassland pasture and range that resulted from several changes to the questionnaire used in the 2007 and 2012 Censuses of Agriculture. Grassland pasture and range, at 655 million acres in 2012, reached its highest level since the start of the MLU series. Apart from the decline in cropland pasture, the remaining cropland uses, as a whole, increased by roughly 7 million acres (2 percent) over 2007-12.

Figure 1.2.3

**Major uses of U.S. cropland, 1949-2012**

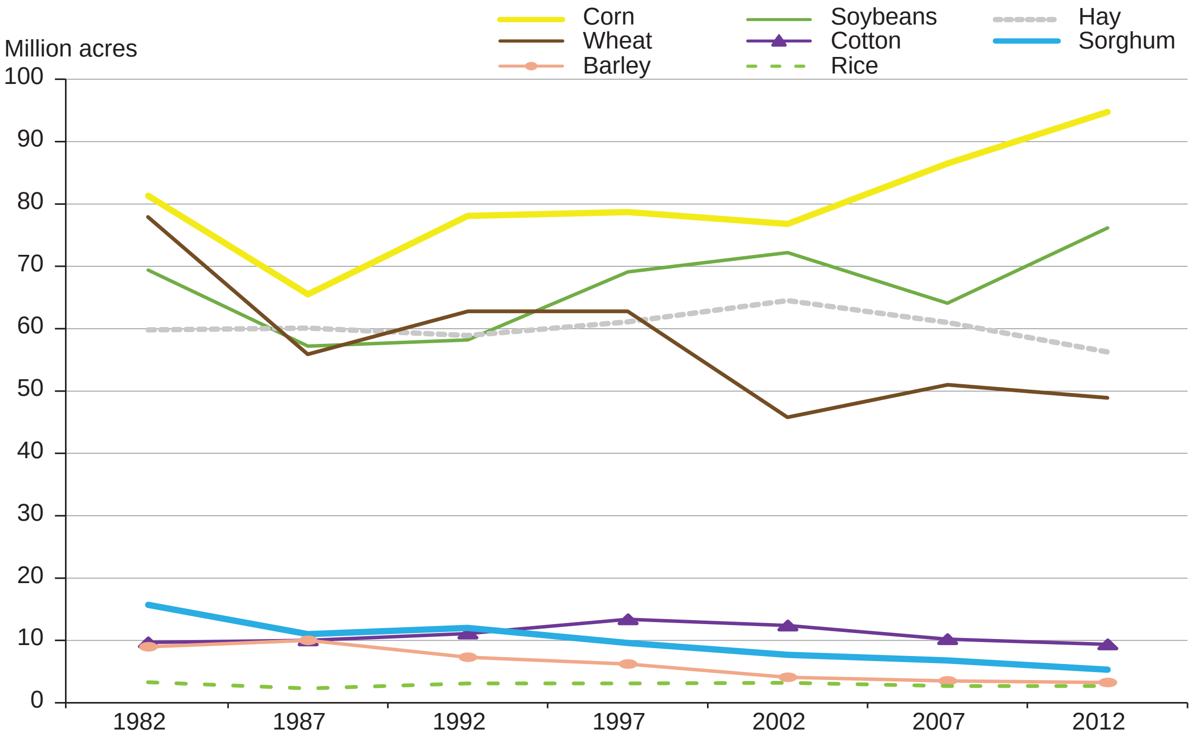



Source: USDA, Economic Research Service calculations drawing on data from USDA, National Agricultural Statistics Service and USDA, Farm Service Agency. See sources and reference list in Bigelow and Borchers (2017) for detailed source descriptions.

Three competing influences explain the recent changes in non-pastured cropland acreage. First, 2007-12 was a period marked by increasing prices for major commodities, particularly corn, incentivizing farmers to devote additional land to crop production. Offsetting increases in harvested cropland acreage over this period were increases in failed and idled cropland. These two latter changes are, at least in part, attributable to the severe droughts that afflicted several leading crop-producing States in 2011 and 2012 (see chapter 3.16, "Farm-Level Adaptation to Drought Risk"). Failed cropland increased by 3 million acres (38 percent) over 2007-12, while idled cropland increased by 2 million acres (1 percent). The idled cropland category, however, also includes land enrolled in the Conservation Reserve Program (CRP), which fell by over 7 million acres over the same period (see chapter 3.23, "Conservation Reserve Program"). Disregarding CRP land, then, a 9-million-acre increase in idled cropland accompanied the droughts experienced during this period. Last, fallowed cropland acreage also continued its long-term decline in recent years, a trend that is partly attributable to increases in the adoption of reduced-tillage practices, which are an alternative means to enhance soil moisture in arid regions (see chapter 2.12, "Crop Production Management: Tillage Practices").

Figure 1.2.4

**Principal U.S. crops harvested, 48 contiguous States, 1982-2012**




Source: USDA, Economic Research Service calculations drawing on data from USDA, National Agricultural Statistics Service and other sources. See sources and reference list in Bigelow and Borchers (2017) for detailed source descriptions.

The mix of crops grown in the United States can change in response to market incentives and agricultural policy and programs (figure 1.2.4). Increases in U.S. soybean plantings from 1995 to 2013, for instance, are contemporaneous with a large increase in exports. The decline in wheat plantings in that time period, on the other hand, occurred alongside increased foreign competition, CRP participation in wheat-producing areas, and improved corn and soybean seed varieties that allow these crops to be planted in areas previously used primarily for wheat. The use of crops as a biofuel input source has also contributed to the large gains in planted corn acreage—the main input in ethanol production—in recent decades (see, e.g., Wallander et al., 2011; Beckman et al., 2013; and chapter 3.18, "Renewable Energy").

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# Chapter 1.3—Farmland Values

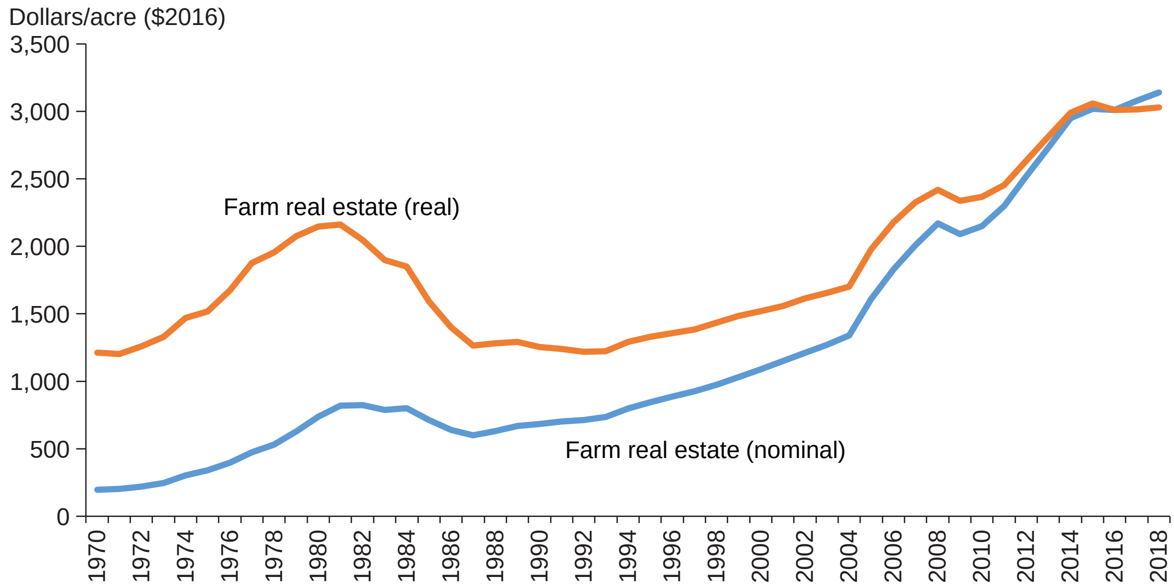
Daniel Bigelow

- Starting in the early 2000s, a boom in farmland values took place, with average U.S. farm real estate value nearly doubling in inflation-adjusted terms.
- Since 2015, however, the value of cropland has declined by nearly 5 percent, while pastureland values have been relatively stable.
- Cropland values in the Corn Belt and Northern Plains, where many farmers specialize in cash grain commodity production, have exhibited the largest recent declines.

In recent years, farm real estate (land and buildings) has accounted for more than 80 percent of total farm asset value. Farmland values are a useful barometer for measuring the overall financial well-being of the farm sector. During the farm financial crisis of the 1980s, farmland values fell precipitously (figure 1.3.1). After an ensuing period of relative stability and modest growth, inflation-adjusted farm real estate values increased rapidly between 2000 and 2014, a trend that coincided with historically low interest rates and strong farm earnings.

Figure 1.3.1.

**Average nominal and inflation-adjusted U.S. farm real estate values, 1970-2018**



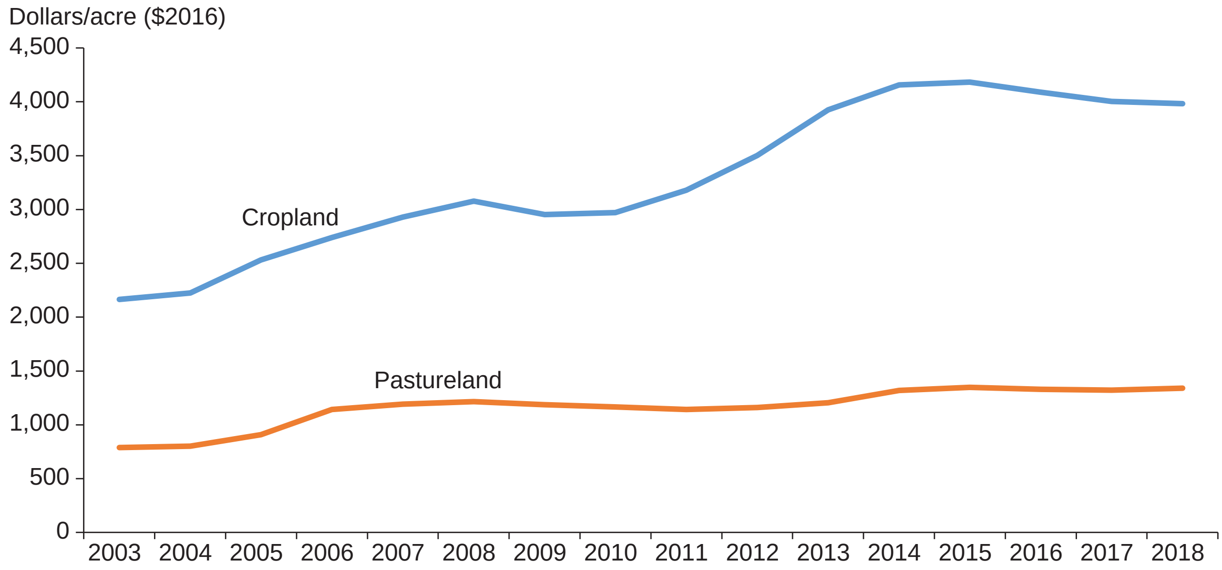

Note: Farm real estate values include the value of land and buildings. Hawaii and Alaska are not accounted for in the above chart. The CPI-U (Consumer Price Index for Urban Consumers) is used to convert nominal values to real (adjusted for inflation) 2016 U.S. dollars.
Source: USDA, Economic Research Service using data from USDA, National Agricultural Statistics Service.

At the national level, cropland values nearly doubled between 2003 and 2018, increasing from an average of $2,165 to $3,983 per acre (in inflation-adjusted 2016 $USD; figure 1.3.2). The value of pastureland has also grown, albeit more modestly. After a short period of decline amid the Great Recession of 2007-08, commodity price increases (particularly for corn and soybeans) spurred the boom in cropland values over 2010-13. However, farm real estate and land value appreciation has slowed over the past few years.

Between 2015 and 2018, the real value of cropland declined by nearly 5 percent. Pastureland values have been more stable, declining by less than 1 percent between 2015 and 2018.

Figure 1.3.2.

**Average inflation-adjusted U.S. farmland values, 2003-2018**




Note: Cropland and pastureland values reflect the value of land only. The chart excludes farmland values for Hawaii and Alaska. The CPI-U Consumer Price Index is used to convert nominal values to real (adjusted for inflation) 2016 U.S. dollars. Inflation adjustments for 2018 are based on the first 6 months of available 2018 data.
Source: USDA, Economic Research Service using data from the USDA, National Agricultural Statistics Service (NASS), *Land Values 2018 Summary*. Data for years prior to 2018 are derived from earlier versions of the NASS *Land Values* report.

Growth in farmland values is contemporaneous with a shift in the expected stream of net returns that owning farmland may yield. This is influenced by factors that affect the economy as a whole, as well as those that are specific to the farm sector. For example, rising farm loan interest rates can put downward pressure on land values because the expected net returns from owning land decline when borrowing costs increase and investment alternatives become more attractive (e.g., Oppedahl, 2017). Expectations of the income stream may also be changing due to decreased commodity prices: at the end of 2017, the ratio of prices received by farmers to production costs was 13 percent lower than in 2013. In addition, 2018 USDA projections indicate that the inflation-adjusted prices of three major crops will either hold constant (wheat) or exhibit modest declines (corn and soybeans) over the next 10 years (USDA, 2018).

Farmland values exhibit considerable regional variation (table 1.3.1). For example, the highest farmland values are generally found in the Corn Belt, Pacific, and Northeast regions. Land values in the Corn Belt are associated with cash-grain commodity prices and growing conditions. Hence, as a result of the 2010-13 commodity price boom, cropland values grew more rapidly in the Corn Belt than in any other region. However, since 2015, the value of cropland in the region has declined as corn and soybean prices have trended back toward their historical average. A similar downward trend in cropland value has taken place in the Northern Plains, another region where values are strongly associated with cash-grain commodity prices and production.

Table 1.3.1.

**Regional farmland values and farmland value trends**

| Region | Cropland, 2018 value and 2014-18 real percent change | | Pastureland, 2018 value and 2014-18 real percent change | | Farm real estate, 2018 value and 2014-18 real percent change | |
|---|---|---|---|---|---|---|
| Appalachia | 3,920 | -1 | 3,350 | -3 | 3,820 | -1 |
| Corn Belt | 6,710 | -9 | 2,470 | 0 | 6,430 | -4 |
| Delta States | 2,820 | 7 | 2,550 | 7 | 2,980 | 7 |
| Lake States | 4,800 | -2 | 2,110 | 3 | 4,890 | 0 |
| Mountain | 1,810 | 2 | 634 | -1 | 1,140 | 1 |
| Northeast | 5,480 | -1 | 3,480 | -4 | 5,100 | -2 |
| Northern Plains | 2,830 | -13 | 1,070 | 7 | 2,170 | -9 |
| Pacific | 6,780 | 10 | 1,650 | -2 | 5,550 | 17 |
| Southeast | 3,990 | 2 | 3,990 | 0 | 3,870 | 1 |
| Southern Plains | 2,020 | 18 | 1,710 | 6 | 2,220 | 18 |

Note: Farm real estate is the value of both land and buildings across all types of farmland. The chart excludes farmland values for Hawaii and Alaska. The percentage changes are based on using the CPI-U Consumer Price Index to convert nominal values to real (adjusted for inflation) 2016 U.S. dollars. Inflation adjustments for 2018 are based on the first 6 months of available 2018 data.
Source: USDA, Economic Research Service using data from USDA, National Agricultural Statistics Service (NASS), *Land Values 2018 Summary*. Data for years prior to 2018 are derived from earlier versions of the NASS *Land Values* report.

In contrast, the relatively high farmland values in the Northeast are mainly due to non-agricultural influences (such as the expansion of urban and suburban land use) that bid up the value of farmland. As a result, cropland values in the Northeast, on average, did not show an uptick stemming from the increase in commodity prices, as they did in cash-grain production areas such as the Corn Belt. The relative dependence of land values on net returns to crop production is captured by patterns in cropland cash rents. For instance, cropland cash rents in the Corn Belt ($204/acre in 2018) are far higher than those in the Northeast ($80.50/acre).

In many regions, the difference in value between cropland and pastureland is stark, with cropland commanding a premium due to the higher per-acre returns associated with crop production and the relative scarcity of high-quality cropland. However, in some areas, particularly the Southeast, land values for these two uses are more comparable, with pastureland values often exceeding the value of cropland. As in the Northeast, the value of pasture in the Southeast is influenced by development pressures from high-density urban areas. Recreational income (e.g., hunting and wildlife viewing) may also play a role in pushing pastureland value above its agricultural production value (Doye and Brorsen, 2011).

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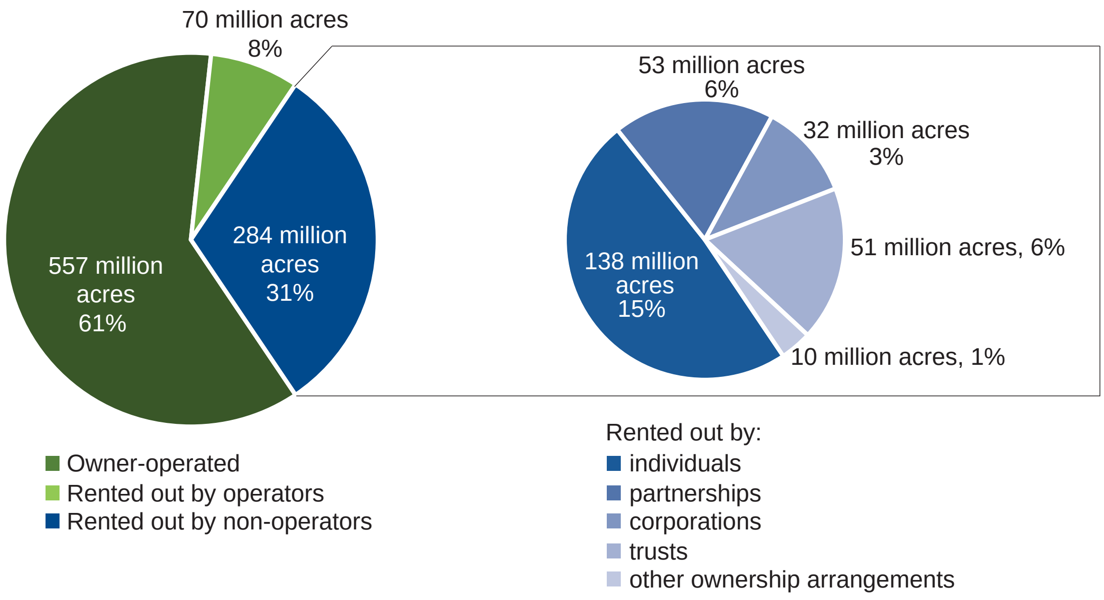
# Chapter 1.4—Farmland Ownership and Tenure

Daniel Bigelow

- In 2014, 61 percent (557 million acres) of U.S. farmland was owned and operated by the same entity. The remaining 39 percent of land was rented out by landowners to tenant operators. Roughly 80 percent of rented land is owned by a non-operator landlord.
- About 54 percent of all cropland was rented out, compared to just 28 percent of pastureland.
- Non-operator landlords, who own 31 percent of all U.S. farmland, own a disproportionate share (52 percent) of land where oil and gas rights have been leased.

Farmland ownership and tenure shape many decisions in the U.S. agricultural sector, including those related to production, conservation, and succession planning. In 2014, 61 percent of the 911 million acres of land in farms in the contiguous United States was owner-operated, meaning that it was owned and operated by the same farming entity (figure 1.4.1). The remaining 39 percent of land was rented out by the landowner to a tenant farm operator.

Figure 1.4.1.
**U.S. farmland ownership, 2014**




Source: USDA, Economic Research Service and National Agricultural Statistics Service, 2014 Tenure, Ownership, and Transition of Agricultural Land survey.

About one-fifth of rented land (8 percent of all farmland) was rented from one farm operator to another. The remainder, about 31 percent of all farmland, was owned and rented out by "non-operator landlords," landowners who are not actively involved in a farm operation but own farmland and rent it out to one or more farm operators. Nearly half of the land rented out by non-operator landlords is owned by individuals, while the remainder is split between partnerships, corporations, trusts, and other ownership arrangements.  In terms of land use, 54 percent of all cropland was rented out in 2014, compared to just 28 percent of pastureland. Small family farms—those with less than $350,000 in gross cash farm

income—are generally less reliant on rental markets, with only 31 percent of land in such operations obtained through renting.

Land tenure arrangements may affect environmental stewardship and adoption of conservation practices, since tenant farmers might lack the incentives to manage land in a way that maximizes long-term land productivity. One way to study this issue is to look at the division of decision making between landlords and tenants for different types of farm decisions. In general, tenants are responsible for day-to-day decisions on the vast majority of land for many aspects of farm management and production, including crop/livestock choices, fertilizer and chemical applications, and harvesting. However, landlords tend to have significantly more involvement in decisions concerning one-season conservation practices and government program participation.[1]

In addition, relative to operator landlords, non-operator landlords are more likely to cede control of decision-making to their tenants for many farm decisions. For example, on land rented from nonoperator landlords, tenants had sole responsibility for fertilizer and chemical application decisions on 93 percent of land, a share that drops to 83 percent for land rented from other operators (table 1.4.1). The disparity is even starker for decisions regarding one-season conservation practice adoption, where landlords are not involved in decisions on 82 percent of non-operator land versus just 67 percent of land rented out by farm operators. This suggests that operator landlords, who may have direct experience with the benefits of conservation practices, are more likely to be engaged with how these practices are adopted on the land they own regardless of whether or not they are currently operating the land.

Table 1.4.1.

**Tenant responsibility for decisions by landlord type and production/management practice, 2014**

| | Non-operator landlords (percent) | Operator landlords (percent) |
|---|---|---|
| Fertilizer and chemicals | 93 | 83 |
| Cultivation practices | 91 | 83 |
| Crop/livestock choices | 93 | 86 |
| Harvesting | 95 | 89 |
| Marketing | 87 | 84 |
| Crop insurance | 83 | 83 |
| One-season conservation practices | 82 | 67 |
| Government program participation | 70 | 58 |

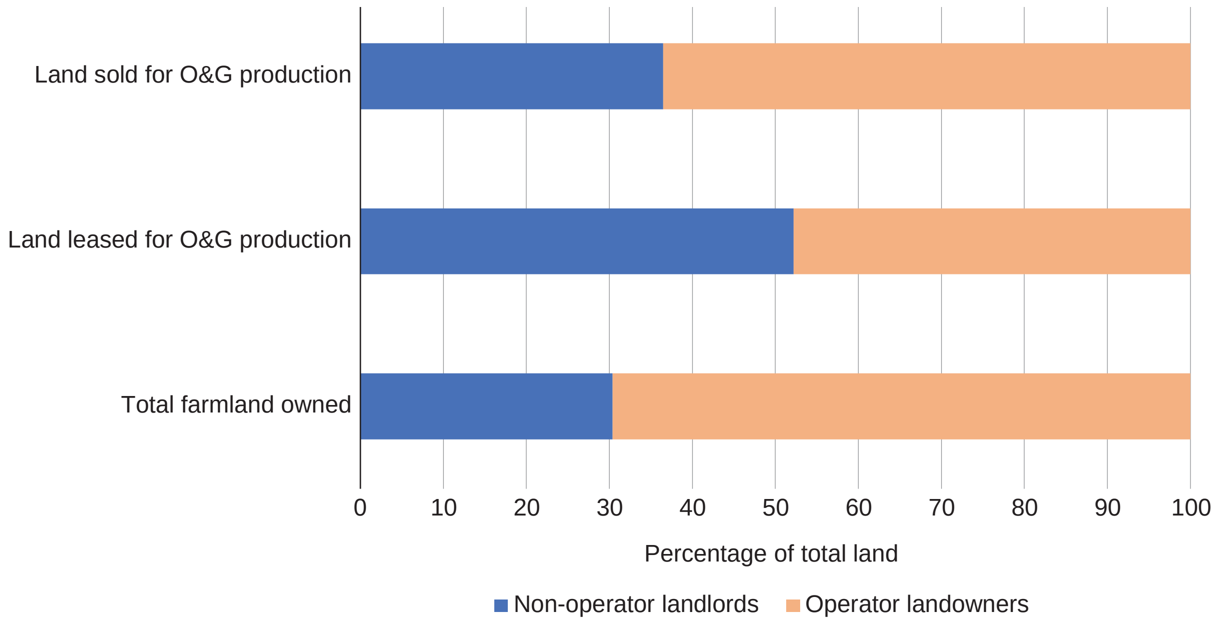
Note: The percentages in the table represent the percentage of total rented acres for the landlords who responded to the decision section of the 2014 TOTAL questionnaire. Values in the table represent the percentages of rented acres characterized by situations where decisionmaking was solely the responsibility of the tenant. “One-season conservation practices” include reduced tillage, no till, cover cropping, and other practices that may vary from season to season. Government programs accounted for in the “Government program participation” category include both commodity and conservation programs. It is not possible to determine if the respondents actually adopted conservation practices or enrolled in Government programs.
Source: USDA, Economic Research Service and National Agricultural Statistics Service 2014 Tenure, Ownership, and Transition of Agricultural Land (TOTAL) survey.

[1]A similar question was asked in the TOTAL survey regarding “permanent” conservation practices, such as the construction of grassed waterways and terraces. The pattern of results from this question are similar to those for one-season conservation practices.

Farmland ownership has gained additional attention in recent years as it relates to the leasing and sale of land for energy production. Non-operator landlords, who owned 31 percent of all U.S. farmland in 2014, control a larger share of land leased for oil and gas production (figure 1.4.2). Specifically, nonoperator landlords, some of whom do not live near the land they rent out, owned 36 percent of farmland on which oil and gas rights had been sold and 52 percent of farmland on which the rights had been leased. This suggests that entities that own farmland, but are not directly involved in its use for agricultural production, may be more likely to exercise nonagricultural use rights to gain access to additional streams of income.

Figure 1.4.2.

**Oil and gas (O&G) production rights sales and leases by ownership type**




Source: USDA, Economic Research Service and National Agricultural Statistics Service; 2014 Tenure, Ownership, and Transition of Agricultural Land survey.

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# Chapter 1.5—Agricultural Productivity and Sources of Growth in the U.S. Farm Sector

Sun Ling Wang

- By 2015, U.S. farm output was about 2.7 times its 1948 level, growing at an average annual rate of 1.48 percent.
- Since aggregate input use increased only 0.1 percent annually, the positive growth in farm sector output was due almost entirely to increased productivity, which grew at an average annual rate of 1.38 percent.
- The composition of the input mix has changed markedly, shifting away from labor and land toward machinery and intermediate goods such as fertilizer and pesticides.

According to ERS's agricultural productivity accounts (USDA, Economic Research Service, 2017), in 2015, the U.S. farm sector used about 75 percent less labor input and 25 percent less farmland than in 1948.[1] Nevertheless, total agricultural production has nearly tripled over this 67-year span. The ability to produce more with much less farmland and labor is attributed mainly to the advancement in agricultural productivity, which is mostly driven by innovations in animal and crop genetics, chemicals, equipment, and farm organization.

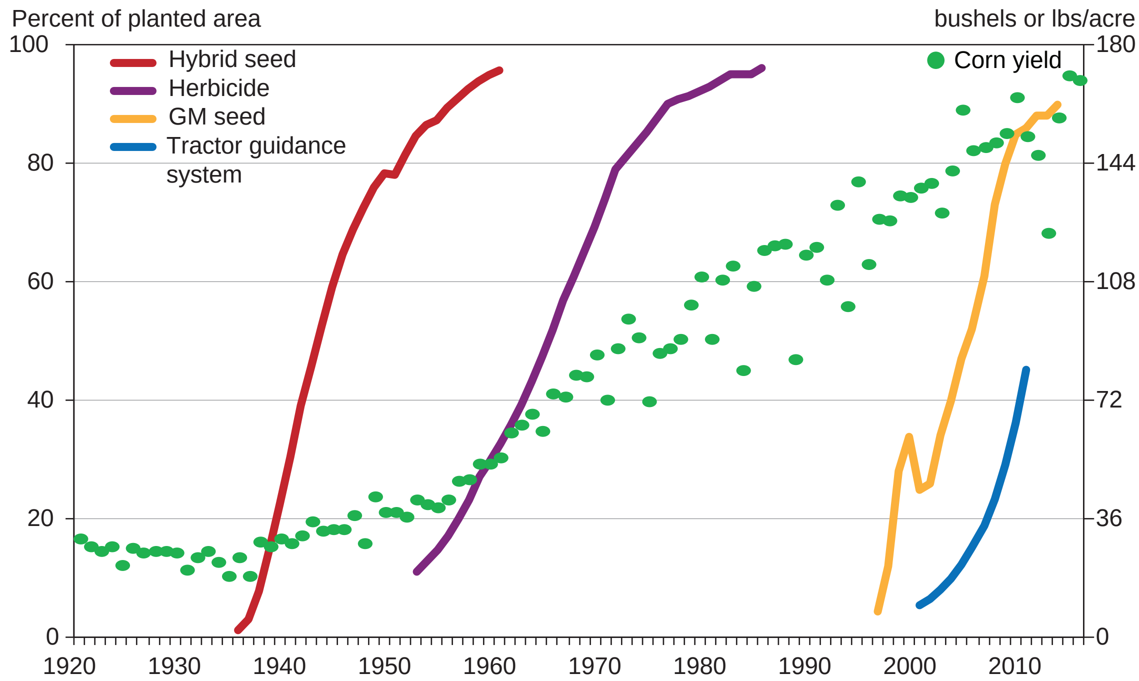
Productivity can be measured by a single factor, like corn production per acre (yield or land productivity) or per unit of labor (labor productivity). But such measures can be misleading. For example, yields could increase through technology adoption or simply because farmers are adding more of other inputs, such as chemicals or machinery. Average national corn yield rose from around 30 bushels per acre in the 1930s to nearly 180 bushels per acre in the present decade. While this sustained growth in corn yield was driven mostly by the development and rapid adoption of successive biological, chemical, and mechanical innovations (fig. 1.5.1; also see chapter 2.7, "Biotechnology and Seed Use for Major U.S. Crops"), it was also due in part to heavier use of non-land inputs. Properly accounting for all input changes when measuring agricultural productivity is important to better understand the sources of growth. USDA's Economic Research Service (ERS) develops measures of total factor productivity (TFP), which account for the use of all inputs under the control of farmers in the production of all commodities (USDA-ERS, 2017). Specifically, TFP growth is the difference between the growth of aggregate output and the growth of all inputs taken together. TFP, therefore, measures changes in the efficiency with which inputs are transformed into outputs.

According to ERS measures, U.S. agricultural output has grown significantly since 1948. By 2015, U.S. farm output was about 2.7 times its 1948 level, growing at an average annual rate of 1.48 percent. Aggregate input use increased only 0.1 percent annually over this time span. Therefore, the positive growth in farm-sector output was due almost entirely to growth in total factor productivity, which averaged 1.38 percent annually (fig. 1.5.2). Since productivity growth is a measure of output growth that cannot be explained by input growth, we discuss the patterns of output and input growth first to better understand growth of TFP and its importance to output growth.

[1]Farmland consists primarily of land used for crops, pasture, or grazing but also includes acres of idled cropland and woodland. In the U.S. agricultural productivity accounts, land stock is measured as the real value of total farmland, which is nominal land value deflated by a land price index from ERS's productivity accounts. In addition, the land stock is also adjusted by quality differences across counties and States.

Figure 1.5.1

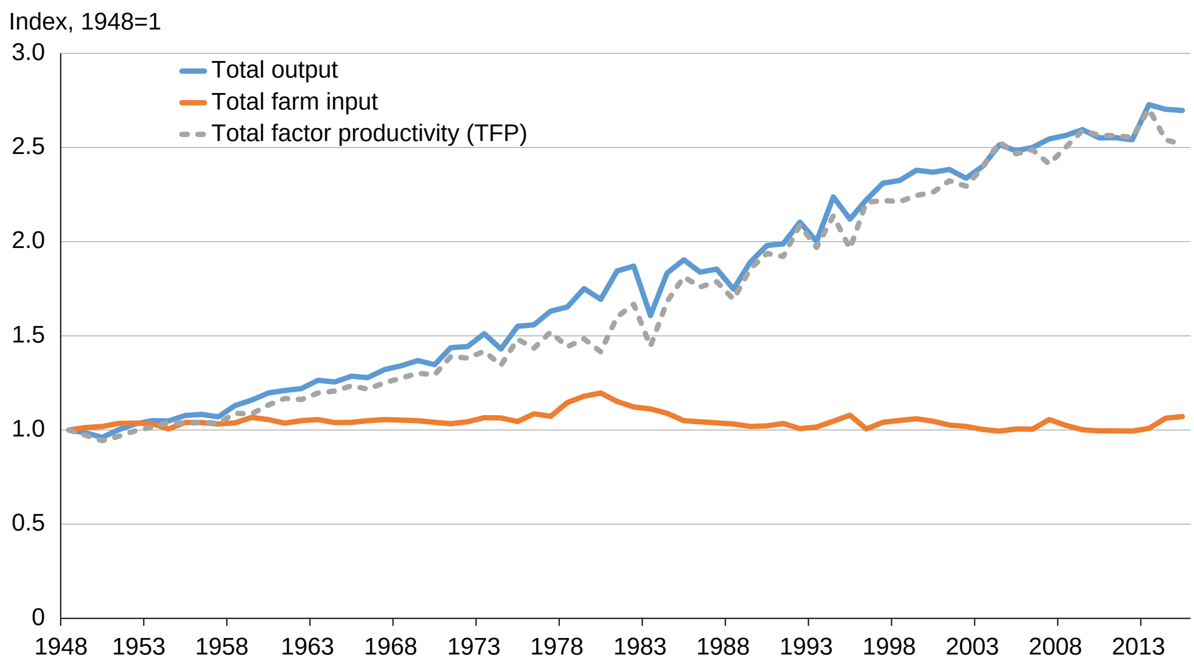
**Effect on corn yields as different innovations become adopted, 1920-2014**




Note: GM = genetically modified.
Source: USDA, Economic Research Service analysis using data from the National Agricultural Statistics Service, Agricultural Statistics yearbook and the Agricultural Resource Management Survey.

Figure 1.5.2

**TFP growth accounted for most of the U.S. agricultural output growth between 1948 and 2015**



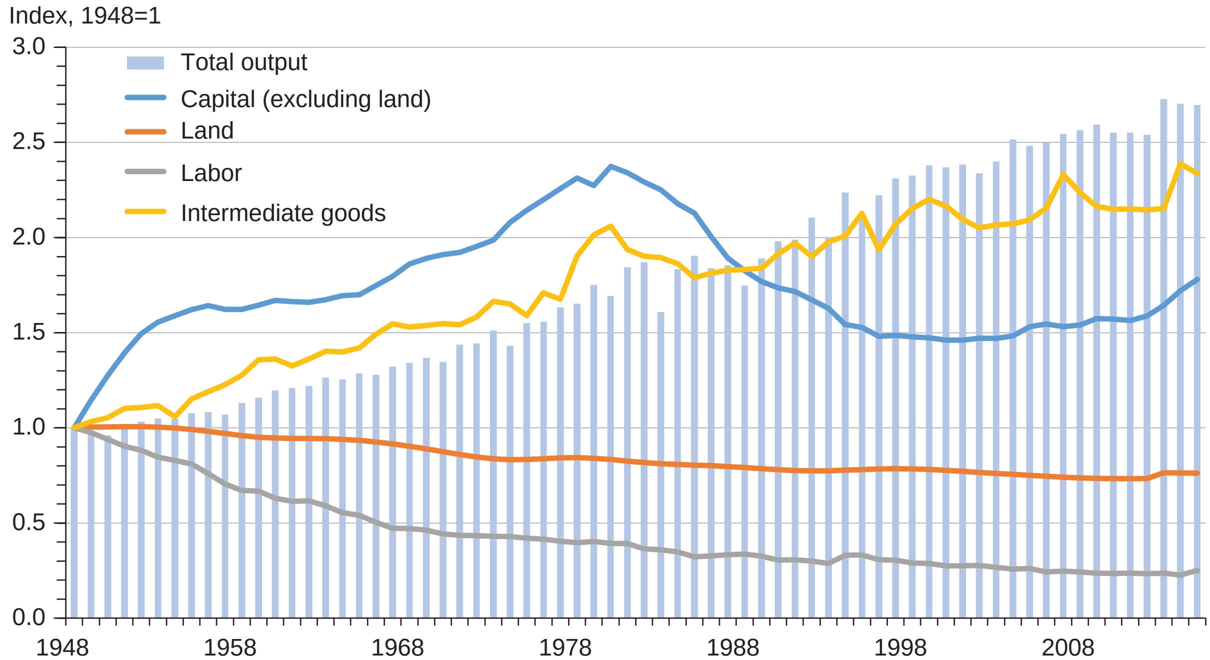

Source: USDA, Economic Research Service, “Agricultural Productivity in the U.S.” series.

## Patterns in Output, Input, and Productivity Growth

Output growth derives from growth in the use of inputs (capital, land, labor, and intermediate goods) and TFP. Input growth has been the main source of economic growth for the U.S. aggregate economy and for most sectors, but the agricultural sector is different (Jorgenson et al., 2014). While total farm output grew 170 percent from 1948 to 2015, total inputs used in agriculture grew by only 7 percent. Nevertheless, the input composition changed markedly, shifting from labor and land toward machinery and intermediate goods (including energy, agricultural chemicals, purchased services, and other materials) (fig. 1.5.3). Between 1948 and 2015, labor and land inputs declined by about 75 and 25 percent, respectively, while intermediate goods and capital (excluding land) grew by 134 percent and 78 percent, respectively.

Figure 1.5.3

**Inputs composition has changed over time**




Note: Data are expressed with an index that is calculated relative to the data in 1948, where data in 1948 are set to equal 1. Intermediate goods include feed and seed, energy use, fertilizer and lime, pesticides, purchased services, and other materials used.

Source: USDA, Economic Research Service, "Agricultural Productivity in the U.S." series.

### *Labor*

Farm labor fell consistently from 1948 until more recent years. Productivity growth in U.S. agriculture is all the more remarkable given labor's long-term contraction. Over 1948-2015, agricultural labor declined on average 0.46 percent each year—a rate unmatched by any other economic sector. The decline in farm labor (both farmers and hired laborers) occurred as workers sought higher wages and other income opportunities in the nonfarm sector, and/or as farmers relied more on machinery use and purchased services—including custom machinery work and contract labor service  (Wang et al., 2015).

## Capital (excluding land)

Capital input (including the flow of services from farm machinery, service buildings, and inventory) in agriculture increased sharply just after WWII, reflecting rapid mechanization in U.S. agriculture. During 1973-79, U.S. agriculture expanded rapidly, fueled by a growth in exports. Agricultural exports continued to grow until 1981. Real (inflation-adjusted) interest rates also fell or remained very low between 1975 and 1980—which decreased the cost of investment. As a result, farmers invested more in farm machinery, service buildings, and inventories. However, in the early 1980s, an appreciating U.S. dollar slowed agricultural exports. Declining demand for U.S. agricultural commodity exports and rising borrowing costs reduced farmers' incentives for further investment in farm machinery and structures. Capital investment declined between 1979 and 1986 and remained stable until the 2000s, when rising agricultural commodity prices and declining real interest rates once again spurred increased investment in machinery and service buildings (see Wang et al., 2015, for more detailed discussion.)

## Land and intermediate goods

Land[2] input has decreased consistently at an average rate of -0.41 percent per year. Over 1948-2015, declining land use put downward pressure on output growth, contributing -0.05 percentage points to output growth per year, on average (table 1.5.1). The positive growth in intermediate goods (fertilizer, pesticides, fuel, etc.) largely reflects the increasing substitution of those inputs for land and labor. Intermediate goods' contribution to output growth averaged 0.6 percent per year over 1948-2015. During 1973-79, when strong export demand fueled dramatic growth in agricultural output that outpaced TFP growth, the growth of intermediate goods contributed 1.65 percentage point per year to output growth. Overall, growing use of intermediate goods offset the negative contributions of labor and land, making the contribution of all inputs essentially flat (0.1 percent) over 1948-2015.

## Total factor productivity growth

TFP growth measures output growth that cannot be explained by growth in inputs, such as innovations in onfarm tasks, changes in the organization and structure of the farm sector, improvements in animal and crop genetics, or other embodied and disembodied technical changes.[3] Between 1948 and 2015, TFP grew at 1.38 percent per year on average. As a result, by 2015, U.S. farm-sector productivity was 152 percent above its 1948 level. With total inputs (including land, labor, capital, and intermediate inputs) growing by merely 7 percent, productivity growth nearly single-handedly led farm output to grow 170 percent above its 1948 level.

Long-term TFP growth is mainly driven by technical change, which is primarily fueled by research and development (R&D) investment from public and private sectors (see chapter 1.6, "Agricultural Research and Development," for more details). It can also be enhanced by public infrastructure, extension, and technology spillover from other sectors or neighboring regions (Wang et al., 2015). Yet, in the short term, estimated TFP can fluctuate considerably from year to year, largely in response to transitory events—such as bad weather and pest outbreaks—or to changes in input use affected by macroeconomic activities or short-term policies. Eventually, TFP growth will return to its long-term trend following these temporary shocks.

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[2]See Wang et al. (2015) and Ball et al. (2016) for more details regarding how land input is measured in U.S. agricultural productivity accounts.

[3]Embodied technical change (ETC) originally referred to the technological advances embodied in the capital goods that make equipment work faster or better in some way. This term can be applied to other inputs when the quality of that input is improved. Disembodied technical change is technical change not associated with any particular input.

## Sources of Agricultural Output Growth

In addition to long-term trends, ERS also examines the sources of agricultural output growth—apportioning increases in output among changes in inputs (both quantities and quality/composition) and TFP—for the entire period and in 12 subperiods (defined by business cycles in accordance with fluctuations in the overall U.S. economy) (table 1.5.1).

Between 1948 and 2015, farms shifted to higher quality labor, mainly due to a more highly educated labor force. Increased labor quality made a positive contribution to output growth in 11 of 12 subperiods (table 1.5.1). On average, labor quality through changes in farm labor's educational attainment and other demographic characteristics contributed to output growth at 0.12 percentage points a year, offsetting part of the contraction in labor quantity. Still, over the entire period, the decline in overall labor input contributed negatively to output growth by nearly -0.5 percent per year. On the other hand, while the changes from durable equipment, service buildings, and inventory (capital, excluding land) made positive contributions to output growth in 9 of 12 subperiods, shrinking land use still made overall contribution of aggregate capital (including land) to output growth of -0.04 percentage points per year. Growth in intermediate goods contributed positively to output growth in 9 of 12 subperiods and accounted for about two-fifths of output growth for the entire period, offsetting negative contributions from labor and capital to output growth.

Table 1.5.1

**Sources of growth in U.S. farm sector, 1948-2015 (average annual growth rates in percent)**

| | 1948-2015 | 1948-1953 | 1953-1957 | 1957-1960 | 1960-1966 | 1966-1969 | 1969-1973 | 1973-1979 | 1979-1981 | 1981-1990 | 1990-2000 | 2000-2007 | 2007-2015 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Output growth | 1.48 | 0.96 | 0.49 | 3.72 | 1.12 | 2.24 | 2.50 | 2.45 | 2.57 | 0.79 | 1.79 | 1.03 | 0.72 |
| Sources of growth | | | | | | | | | | | | | |
| Input growth | 0.10 | 0.66 | -0.03 | 0.75 | -0.09 | 0.00 | 0.36 | 1.69 | -1.21 | -1.32 | 0.24 | 0.11 | 0.20 |
| Labor | -0.46 | -0.83 | -1.11 | -0.88 | -0.86 | -0.65 | -0.41 | -0.19 | -0.23 | -0.45 | -0.23 | -0.38 | 0.00 |
| Capital (including land) | -0.04 | 0.57 | -0.02 | 0.00 | 0.04 | 0.16 | -0.10 | 0.23 | 0.11 | -0.78 | -0.17 | -0.12 | 0.24 |
| Intermediate goods | 0.60 | 0.92 | 1.10 | 1.62 | 0.73 | 0.48 | 0.87 | 1.65 | -1.09 | -0.09 | 0.64 | 0.60 | -0.04 |
| TFP growth | 1.38 | 0.30 | 0.52 | 2.97 | 1.20 | 2.24 | 2.14 | 0.75 | 3.79 | 2.11 | 1.55 | 0.92 | 0.53 |
| Sources decomposition | | | | | | | | | | | | | |
| Labor | | | | | | | | | | | | | |
| Hours | -0.57 | -1.06 | -1.24 | -0.92 | -1.14 | -0.95 | -0.46 | -0.21 | -0.20 | -0.52 | -0.41 | -0.40 | -0.08 |
| Quality | 0.12 | 0.23 | 0.12 | 0.04 | 0.28 | 0.30 | 0.05 | 0.01 | -0.03 | 0.07 | 0.18 | 0.02 | 0.08 |
| Capital | | | | | | | | | | | | | |
| Capital (excluding land) | 0.01 | 0.55 | 0.12 | 0.13 | 0.10 | 0.36 | 0.18 | 0.23 | 0.22 | -0.69 | -0.17 | -0.07 | 0.15 |
| Land | -0.05 | 0.02 | -0.14 | -0.13 | -0.06 | -0.20 | -0.28 | 0.01 | -0.12 | -0.09 | 0.00 | -0.05 | 0.09 |
| Intermediate goods | | | | | | | | | | | | | |
| Quantity | 0.64 | 1.01 | 0.91 | 1.74 | 0.76 | 0.26 | 0.98 | 1.89 | -1.51 | -0.02 | 0.61 | 0.63 | 0.15 |
| Composition | -0.04 | -0.09 | 0.20 | -0.12 | -0.03 | 0.23 | -0.11 | -0.24 | 0.41 | -0.07 | 0.03 | -0.03 | -0.19 |

Notes: The subperiods are measured from cyclical peak to peak in aggregate economic activity. Labor, capital, and intermediate inputs aggregate across different attributes within each input aggregate, including gender, age, educational attainment, and employment types for labor; durable equipment, service buildings, land, and inventories for capital; and feed/seed, energy, fertilizers, pesticides, purchased services and other materials for intermediate goods. The contribution of an input aggregate to growth reflects changes in the quantity and quality (composition of specific components) of the aggregate.

Source: USDA, Economic Research Service, "Agricultural Productivity in the U.S." series, updated October 2017.

During 1948-2015, the net contribution of all inputs was 0.1 percentage point per year, leaving TFP growth the major source of output growth in all but the 1948-1953 and 1973-79 subperiods. Since the United States is one of the largest producers and consumers in the world agricultural commodity market, sustainable productivity growth in the U.S. farm sector is critical to global food security. Given that innovation fueled by R&D is the major driver of productivity growth (see chapter 1.6, "Agricultural Research and Development," for more discussion), steadily growing investment in agricultural research is essential if agricultural production is to meet growing worldwide demand.

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# Chapter 1.6—Agricultural Research and Development

Paul Heisey

- Both private and public sectors help fund agricultural research and development (R&D), but due to its rapid growth, private spending is now much greater than public spending—which fell in real terms between 2006 and 2014. Private research spending on agricultural input R&D alone—not including food research—surpassed total public spending in 2010.
- In 2014, the private sector funded over three-quarters of all food and agricultural R&D in the United States.
- Public and private agricultural R&D investments are generally complementary rather than competitive. For example, in 2014, the private sector dominated farm machinery and food manufacturing research, while the public sector performed nearly all U.S. research on the environment/natural resources and human nutrition/food safety.

The growth in agricultural productivity over the past seven decades (see chapter 1.5, "Agricultural Productivity and Sources of Growth in the U.S. Farm Sector") can be attributed largely to investments in agricultural research and technology development (OECD, 2016; Wang et al., 2013). Genetic improvements in crops and livestock, improved agricultural chemicals and fertilizers, more efficient agricultural machinery, and cost reductions in farm management techniques have transformed U.S. agriculture.

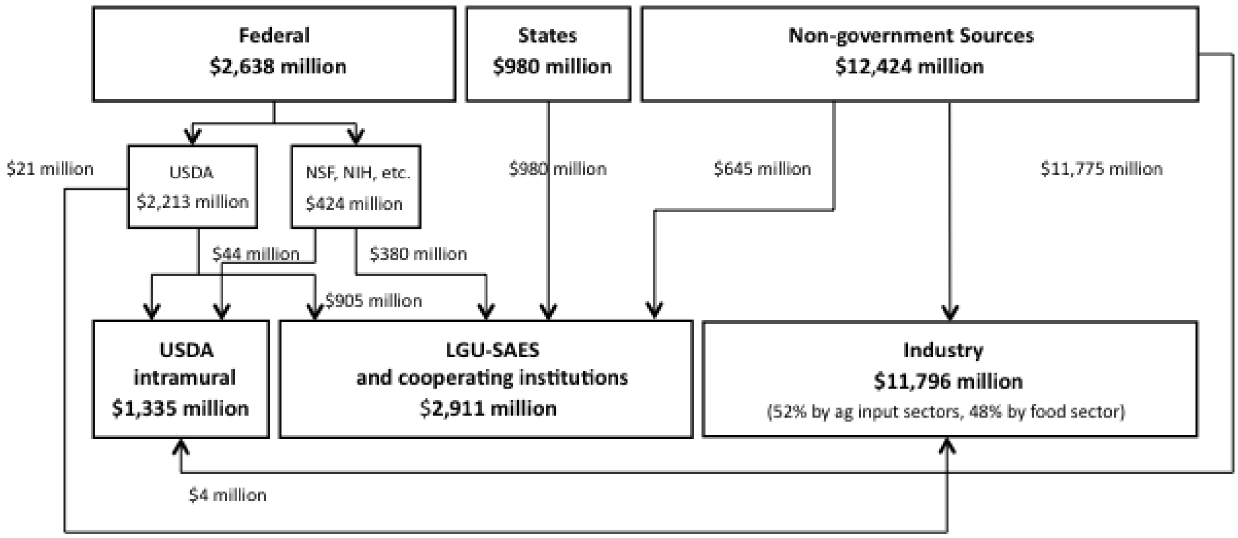
As agricultural productivity has increased, the agricultural research portfolio has expanded to include areas such as the environment; the quality, safety, and nutritional value of food products; the treatment of farm animals; the livelihoods of farm workers; and the resilience of rural communities. These objectives have refocused public agricultural research to include the characteristics of agricultural products and the impacts of production methods, in addition to technology development. Corporate agribusiness has played an increasingly larger role in developing new technologies and providing services for agriculture.

## Multiple Institutions Operate in a Complex System

Agriculture has benefited from a unique Federal-State partnership in agricultural research and extension, with a history of collaboration with the private sector. The *funders* of agricultural and food research include nongovernmental sources—primarily the private business sector, but also foundations and farmer organizations—that provided over three-quarters of the funding in 2014, or about $12.4 billion in real (inflation-adjusted) dollars.[1] The Federal Government—including USDA as well as other agencies such as the National Science Foundation (NSF) and the National Institutes of Health (NIH)—contributed $2.6 billion, and State governments just under $1 billion (fig. 1.6.1).

[1]All estimates of research spending in this chapter are adjusted for inflation to 2012 dollars using the ERS research deflator. Inconsistencies in one of the major series underlying this deflator—faculty salaries for U.S. educational institutions—preclude updating the base year to 2017.

Figure 1.6.1
**Funders and performers of U.S. food and agricultural research in 2014 (in 2012 dollars)**




Note: All estimates are adjusted for inflation and expressed in 2012 dollars using the ERS research deflator. NSF = National Science Foundation; NIH = National Institutes of Health. LGU-SAES = Land Grant Universities/State Agricultural Experiment Stations.
Source: USDA, Economic Research Service based on data from the Current Research Information System; USDA, National Institute of Food and Agriculture; National Science Foundation Federal Funds for Research and Development; and Fuglie (2016).

*Performers* of agricultural research include Federal researchers, who generally study issues of national importance and accounted for about $1.3 billion of research spending in 2014. State-level research at the Land Grant Universities/State Agricultural Experiment Stations (LGU-SAES) and other cooperating institutions, usually other universities, accounted for $2.9 billion. Research at these academic institutions is typically directed at issues of local and regional importance and at fundamental scientific questions.

Industry was the largest performer of food and agricultural research in 2014, at $11.8 billion (fig. 1.6.1). Private-sector research is usually nearest the marketplace. Roughly half of private-sector research was spent in the food sector, where much of it is oriented toward improving food manufacturing processes and developing new food products. The other half goes toward research related to agricultural inputs, which is much more likely to have a direct impact on production agriculture.

The U.S agricultural research system is characterized by numerous links between institutions. State-level institutions receive funds from several Federal agencies other than USDA, and USDA funds State-level institutions through a variety of instruments. The private sector and USDA exchange funds or conduct joint research through grants, cooperative agreements, contracts, and trusts. USDA, State-level institutions, and private firms all transfer technology through the patent-licensing mechanism or research consortia.

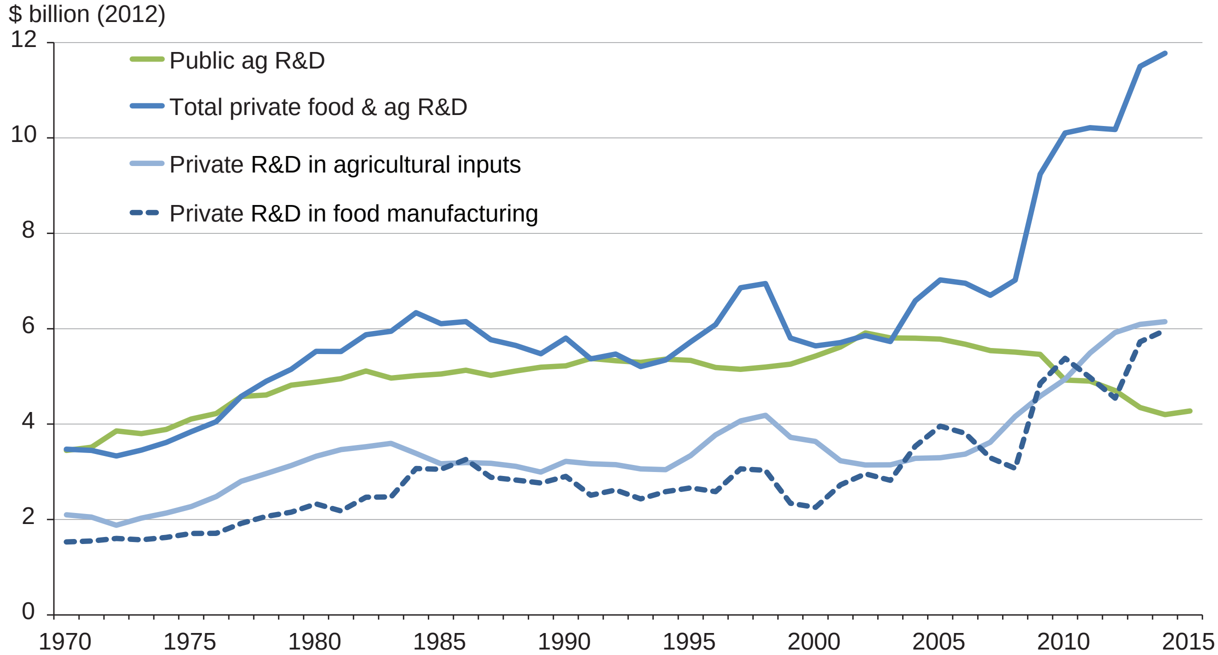
## Private-Sector Research Has Increased While Public Research Has Fallen

Historically, public institutions played a direct role in developing new agricultural technologies and encouraging their commercialization and adoption by farmers. Advances in the biological sciences, broader intellectual property rights protection, and expansion of agricultural markets have stimulated private-sector R&D.

Since about 1980, growth rates in public R&D have been generally low (fig. 1.6.2). Growth in private investment has generally been higher, but with greater variation. In the early 2000s, public and private agricultural research investments began to diverge more rapidly. Total private agricultural and food R&D doubled between 2003 and 2014, while public R&D fell. By 2010, private R&D for agricultural inputs alone surpassed the public level for all agricultural research.

Figure 1.6.2

**Real agricultural research and development (R&D) funding, 1970-2015**




Note: Data are adjusted for inflation and expressed in 2012 dollars.
Source: USDA, Economic Research Service.

## Focus of Private and Public R&D Differs

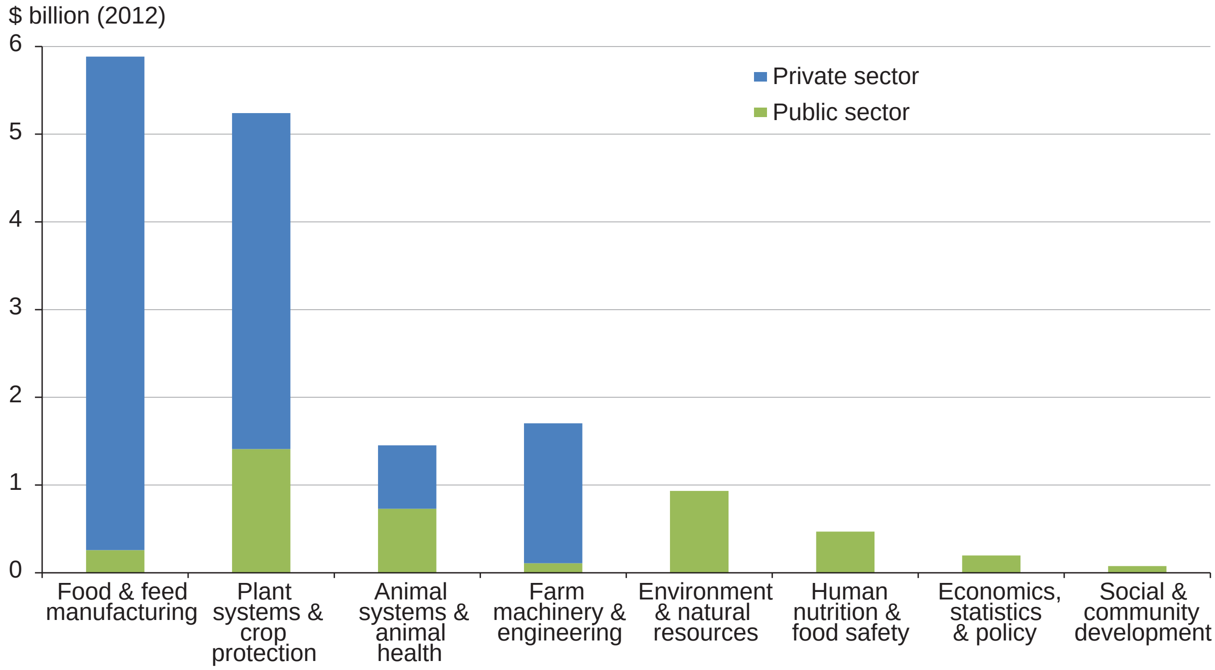
In many ways public and private agricultural research efforts are complementary rather than competitive. Little incentive exists for private firms to pursue research whose results benefit society as a whole rather than the specific innovator. The incentives that encourage firms to fund and perform R&D are *private returns* (i.e., the economic benefits from new products and technologies that can be captured through market sales). But companies cannot capture all the potential economic benefits from R&D activities. Some benefits may accrue to farmers as lower production costs even after higher prices from new technologies have been taken into account. Some R&D benefits may go to consumers in the form of safer or cheaper food. Benefits may go to other firms that develop related applications from the scientific information generated, even from other private research, as private research is only partially protected by intellectual property like patents or by trade secrets. Still other benefits are enjoyed by society as a whole, in the form of better health or improved environmental quality. The *social returns* (benefits to society as a whole) from many kinds of research can be much higher than their private return.

Thus, the private sector focuses mainly on R&D related to marketable goods and technologies. The food industry, which has little impact on agricultural productivity, accounts for the largest category of private agricultural R&D. Much food industry R&D is directed toward product development and marketing

research. The private sector also dominates farm machinery research. On the other hand, public-sector research addresses applied areas with large social benefits, such as environmental protection, nutrition, and food safety (fig. 1.6.3).

Figure 1.6.3

**Composition of public and private food and agricultural R&D by subsector in 2014**




Note: Data are adjusted for inflation and expressed in 2012 dollars.
Source: USDA, Economic Research Service using data from USDA, National Institute of Food and Agriculture (NIFA), Research, Education, and Economics Information System; and Fuglie (2016).

Both private- and public-sector R&D is directed at the broad general areas of plant and animal research. Private plant research has grown very fast. In the mid-2000s public and private plant research expenditures were roughly equal; by 2014, private investment was over 2.5 times more than public investments in plant research. Within private plant research, crop seed and biotechnology investment has grown particularly rapidly. Gene transfer technologies have enhanced researchers' abilities to tailor crops for specific uses, such as resistance or tolerance to diseases, pests, herbicides, or environmental conditions such as drought (see chapter 2.7, "Biotechnology and Seed Use for Major U.S. Crops"). Broader intellectual property protection, such as the expansion of the right to patent crop varieties, has also stimulated private seed-biotechnology research investment. The share of private crop seed and biotechnology research has grown as the share of agricultural chemical research has fallen, in part because of the development of combined crop seed and agricultural chemical technologies, such as herbicide-tolerant varieties. New technologies such as gene editing may eventually enhance the development of improved crop varieties and livestock breeds even further.

In the longer run, public and private research investments are complementary, even in the area of crop research, though there may be short-run substitution of public and private research funding. For some time, public crop breeders have focused more on "basic plant breeding research" and "germplasm enhancement," while private-sector researchers concentrate on downstream development of cultivars that are marketed directly to farmers. As private-sector investment in crop research has grown, the public sector has reallocated its research portfolio toward more basic biological research or to other research for

which private firms cannot capture all the benefits through the prices they charge. Public research generally operates on a longer timeframe as well, allowing it to address problems with lower probabilities of short-term payoff.

U.S. agricultural productivity growth has been marked by large increases in aggregate output with almost no change in aggregate input use (see chapter 1.5, “Agricultural Productivity and Sources of Growth in the U.S. Farm Sector”). R&D has been a major driver of agricultural productivity growth (OECD, 2016), and the research-related changes in agricultural technology that have accompanied productivity growth have therefore influenced both input use and the environmental impacts of agriculture.

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# Group 2: Farm Production and Management

## Chapter 2.7—Biotechnology, Seed Use, and Pest Control for Major U.S. Crops

Seth Wechsler

- Adoption rates for genetically engineered (GE) crops rose rapidly in the years following their commercialization in 1996. As of June 2018, approximately 9 out of every 10 acres of domestic corn, cotton, soybeans, sugarbeets, and canola were cultivated using GE seeds; approximately 80 percent of U.S. corn and 82 percent of cotton acreage was planted with seeds that were "stacked," or genetically engineered to be both herbicide tolerant (HT) and insect resistant (Bt).
- The commercialization of Bt crops led to a decrease in synthetic soil-applied and foliar insecticide use; for example, insecticide use among U.S. corn farmers fell by over 80 percent from 1996 to 2017.
- Initially, the commercialization of HT crops led to increases in glyphosate use and decreases in the use of other herbicides. Recently, the use of glyphosate, and the use of herbicides other than glyphosate, has increased—largely due to the development and spread of glyphosate-resistant weeds.

### Adoption Rates for Genetically Engineered Crops Rose Rapidly in the Early 21st Century

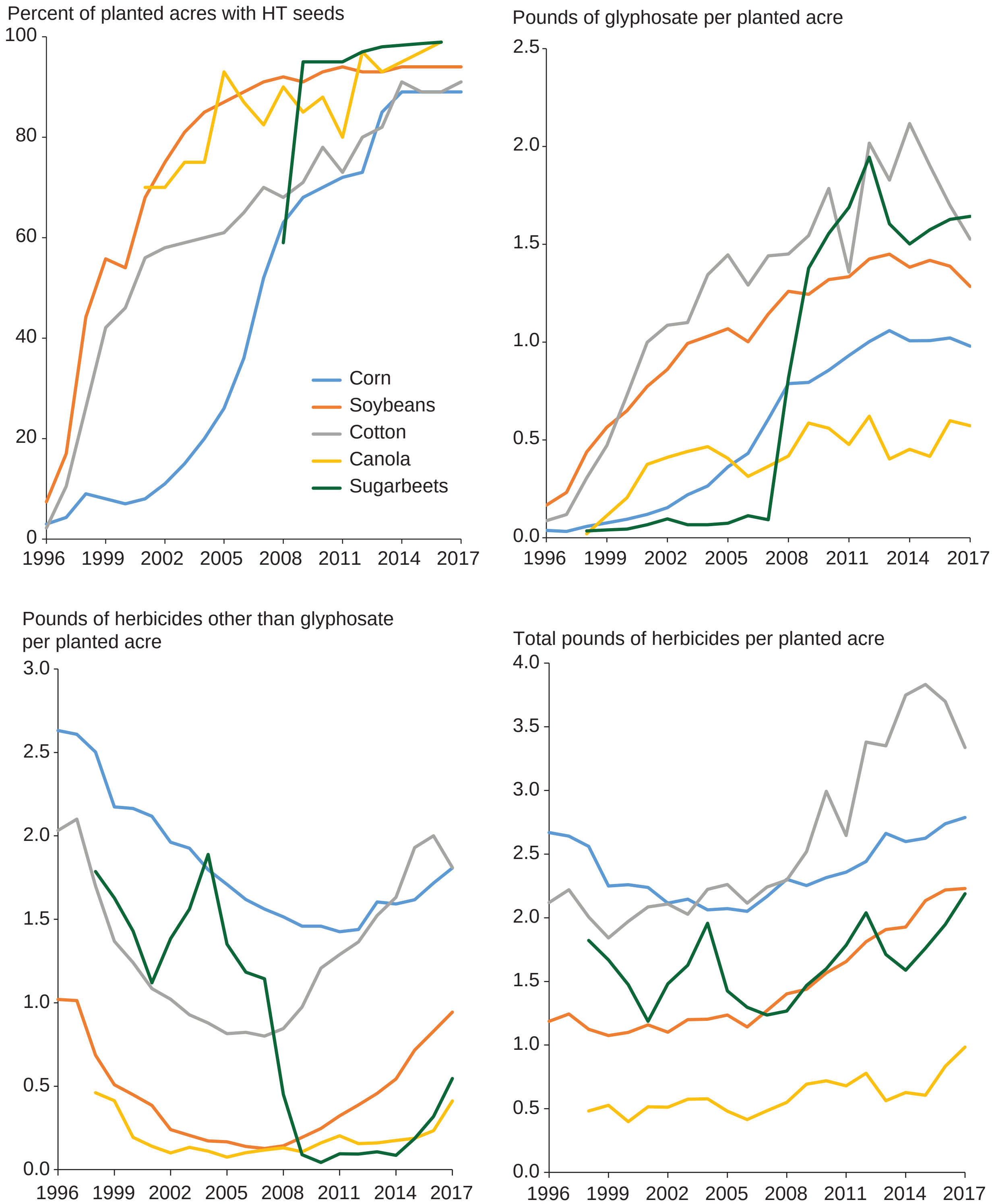
Building on the results of public biomedical research, large life-science companies invested millions of dollars in efforts to develop profitable crop biotechnologies throughout the 1980s. These efforts culminated in 1996 with the commercialization of genetically engineered (GE) corn, soybean, and cotton crops. GE canola was commercialized in 1998. GE alfalfa and sugarbeets were commercialized in 2005.

Herbicide-tolerant, or HT, crops are not damaged when they are sprayed with broad-spectrum herbicides (such as glyphosate or glufosinate) that damage most conventional varieties. Planting HT crops allows farmers to use nonselective, broad-spectrum herbicides throughout the growing season (even after crop emergence). Insect-resistant crops contain genes from a soil bacterium (*Bacillus thuringiensis)* that produces a naturally occurring insecticide. Unlike conventional insecticides, which can be leached from soils or adversely affected by soil pH, the toxins produced by Bt crops are concentrated in plant tissues. So, planting Bt crops helps ensure that insects are controlled throughout the growing season.

Adoption rates for GE crops rose rapidly in the decade following their commercialization. As of 2017, approximately 9 out of every 10 acres of corn, cotton, soybeans, sugarbeets, and canola produced in the United States were cultivated using HT seeds (figure 2.7.1). Approximately 8 of every 10 acres of corn and cotton acres were cultivated using Bt seeds (figure 2.7.2). Although other GE traits have been developed (such as virus, fungus, cold, and drought resistances), crops with HT and Bt traits are the most prominent of the commercially available, genetically engineered varieties. Most GE corn and cotton seeds are "stacked" with both HT and Bt traits. As of 2017, approximately 80 percent of U.S. corn and cotton acreage was planted with stacked seeds (figure 2.7.3).

Figure 2.7.1

**Planting herbicide-tolerant (HT) crops has increased glyphosate use, with mixed effects on non-glyphosate herbicide use, 1996-2017**




Source: USDA, Economic Research Service using data from Fernandez-Cornejo and McBride (2002), Fernandez-Cornejo, Nehring, et al. (2014), Fernandez-Cornejo, Wechsler, and Milkove (2016), USDA, National Agricultural Statistics Service (NASS) June Area Survey, and proprietary USDA data.

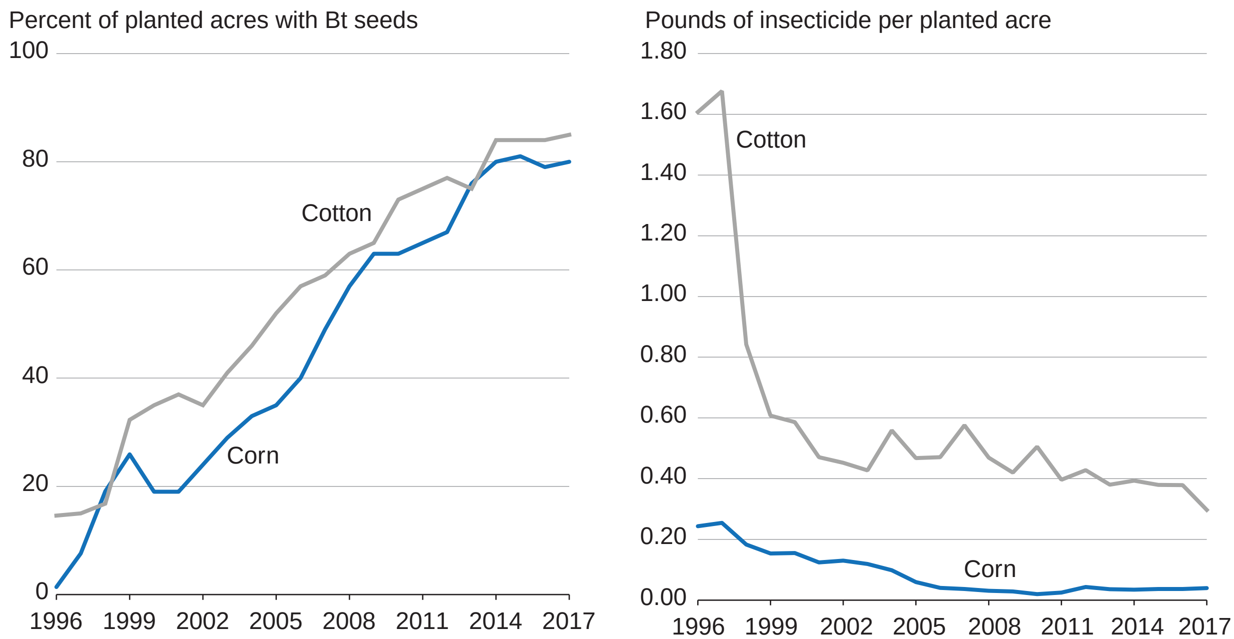
## GE Seed Use Affects Farmers' Pest Control Decisions, Yields, and Operating Costs

Choosing to plant GE seeds can alter farmers' revenue, operating costs, and input use. These impacts vary by crop and production system. However, certain trends are particularly striking. Planting Bt crops tends to increase yields (when insects are present) and decrease insecticide use. For instance, Wechsler and Smith (2018) found that planting rootworm-resistant corn increased U.S. farmers' yields by over 6 bushels per acre (approximately 4 percent) in 2005 and 3 bushels per acre (approximately 2 percent) in 2010, while reducing insecticide use dramatically. From 1996 to 2017, insecticide use among U.S. corn and cotton farmers fell by over 80 percent (figure 2.7.2). In some cases, the widespread use of Bt seeds has suppressed local pest populations (Hutchison et al., 2010). These reductions have benefited many U.S. farmers (not just those planting Bt seeds) and may have contributed to further decreases in insecticide use.

After World War II—which led to the development of growth-regulating herbicides like 2,4-D—and prior to the development of HT varieties, U.S. farmers achieved high levels of weed control using crop rotations, tillage, and herbicide applications. Perhaps because U.S. farmers effectively managed weeds prior to the commercialization of HT seeds, there is mixed evidence as to whether HT adoption increases farmers' yields. For instance, Nolan and Santos (2012), who analyzed field trial data from 2002 to 2007, found no difference in yields on fields planted with HT or conventional corn seeds. Shi, Chavas, and Lauer (2013) found that average corn yields were actually *lower* on fields planted with HT seeds than on fields planted with conventional ones.

Figure 2.7.2

**Planting insect-resistant (Bt) crops has decreased insecticide use, 1996-2017**




Source: USDA, Economic Research Service using data from USDA (2002), USDA (2014b), USDA (2016), USDA, National Agricultural Statistics Service (NASS) June Area Survey, and proprietary USDA data.

There is evidence that planting HT crops simplifies weed management systems, and that this simplification confers time and labor savings to farmers (Gardner et al., 2009). Fernandez-Cornejo, Hendricks, and Mishra (2005) find that HT adoption is associated with increases in off-farm income. However, time and

labor savings can also be employed on the farm, and may partially explain increases in farm size over time. There is evidence that HT adoption benefits farmers by reducing their reliance on tillage for weed control (Fernandez-Cornejo et al., 2012). Reducing tillage can lower fuel, equipment, and labor costs. It can also improve soil structure and increase water infiltration, while reducing soil erosion and nutrient runoff (Wade, Kurkalova, and Secchi, 2016).

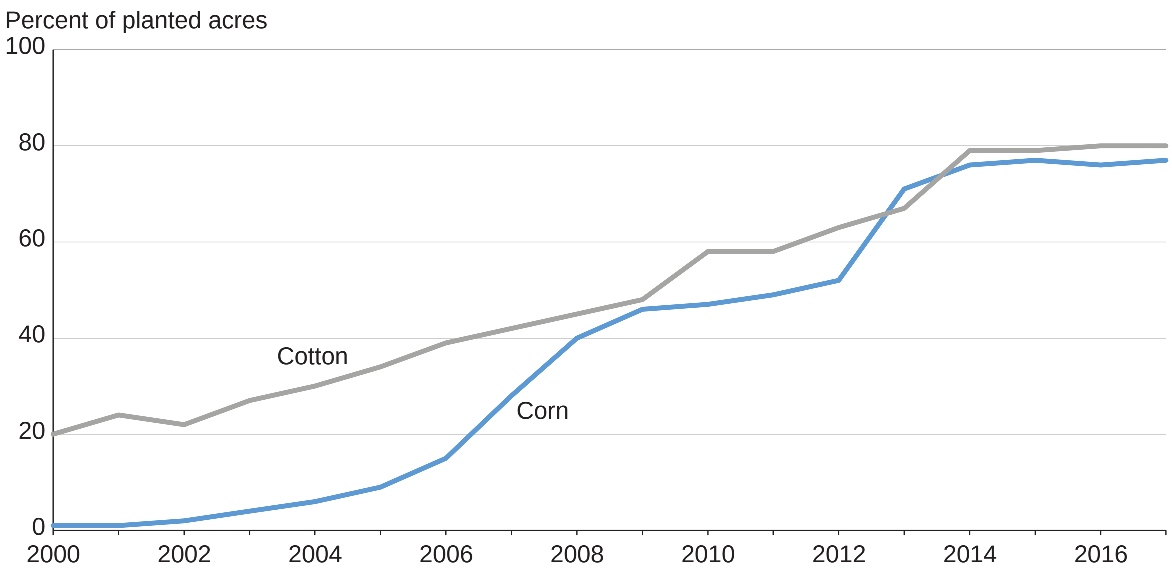
The rapid adoption of HT technologies, and their ubiquity in domestic field crop production, suggests that U.S. farmers benefit from the use of herbicide-tolerant seeds, especially since HT (and Bt) seeds are more expensive than their non-GE counterparts. It is clear that the herbicides used in HT production systems (the vast majority of which are formulations of an active ingredient called glyphosate) provide excellent post-emergent weed control (Wechsler, McFadden, and Smith, 2017). The use of herbicides other than glyphosate decreased by approximately 65 percent over this time period.[1] Many scientists perceived that this shift had environmental and human health benefits because glyphosate is less toxic than many of the herbicides it replaces (Duke and Powles, 2008)

Though herbicide application rates initially declined following the commercialization of HT corn and cotton, these rates have increased over the course of the last decade, in part due to the development and spread of glyphosate-resistant weeds (see chapter 2.8, "Pest Management"). Herbicide application rates increased by over 95 percent on soybeans and over 68 percent on canola from 2006 to 2017 (figure 2.7.1).

Recently, new varieties of GE seeds that are tolerant of the herbicidal active ingredients dicamba and 2,4-D have been commercialized. It remains to be seen how the introduction of these technologies will affect the herbicide use and weed control decisions of U.S. farmers.[1]

Figure 2.7.3

**Share of acres planted with stacked seeds has increased over time**




Note: Stacked seeds have both herbicide-tolerant (HT) and insect-tolerant (Bt) traits.
Source: USDA, Economic Research Service report, *Adoption of Genetically Engineered Crops in the U.S.* (2017).

[1]Several ERS reports contain further information on genetically modified seed use, including *Genetically Engineered Crops in the United States* (ERR-162) and *The Adoption of Genetically Engineered Alfalfa, Canola, and Sugarbeets in the United States* (EIB-163).

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# Chapter 2.8—Pest Management

Richard Nehring

- In 2012, U.S. producers spent over $9 billion on pesticides to control pests such as insects, mites, and weeds.
- The development of herbicide resistance in several weed species has contributed to increased recent herbicide use. From 2010 to 2014, herbicide application rates (per planted acre) rose by 24 percent on U.S. soybeans, 26 percent on wheat, 25 percent on cotton, and 21 percent on corn.
- Weed resistance to newer herbicides has led to expanded use of some older herbicides.

Pests—such as insects, mites, and weeds—can reduce crop yields or the quality of production, while the cost of managing pests can reduce farm profitability. To control pests, farmers rely on pesticides like herbicides, insecticides, and fungicides; pesticides also include soil fumigants, plant growth regulators, defoliants, and desiccants. Pesticides can be synthetic (developed in laboratories and manufactured) or natural (chemical compounds occurring in nature).

## Pesticide Trends

According to U.S. Environmental Protection Agency (EPA) data, U.S. agricultural producers spent over $9 billion on 899 million pounds of pesticide active ingredient in 2012. That was about 32 percent more (in inflation-adjusted terms) than was spent in 2007, and 10 percent more pounds of pesticide active ingredient.[1] Between 2007 and 2012, herbicide expenditures declined from 62 to 59 percent of total pesticide expenditures, but the share of total applied active ingredient weight accounted for by herbicides increased from 54 to 63 percent (see fig. 2.8.1).

U.S. corn, cotton, fall potatoes, soybeans, and wheat account for nearly two-thirds of pesticide quantities applied.[2] Total pesticide applications on these five crops, which fluctuated between approximately 400 and 500 million pounds in the 1980s and 1990s, rose sharply after 2005 and reached 634 million pounds in 2014 (fig. 2.8.2).[3]

Corn accounted for 46 percent of all pesticides (by weight) applied to the five major crops in 2014, and hence nearly one-third of all pesticide applications. The second largest crop, soybeans, accounted for another 31 percent of pesticides applied in 2014.

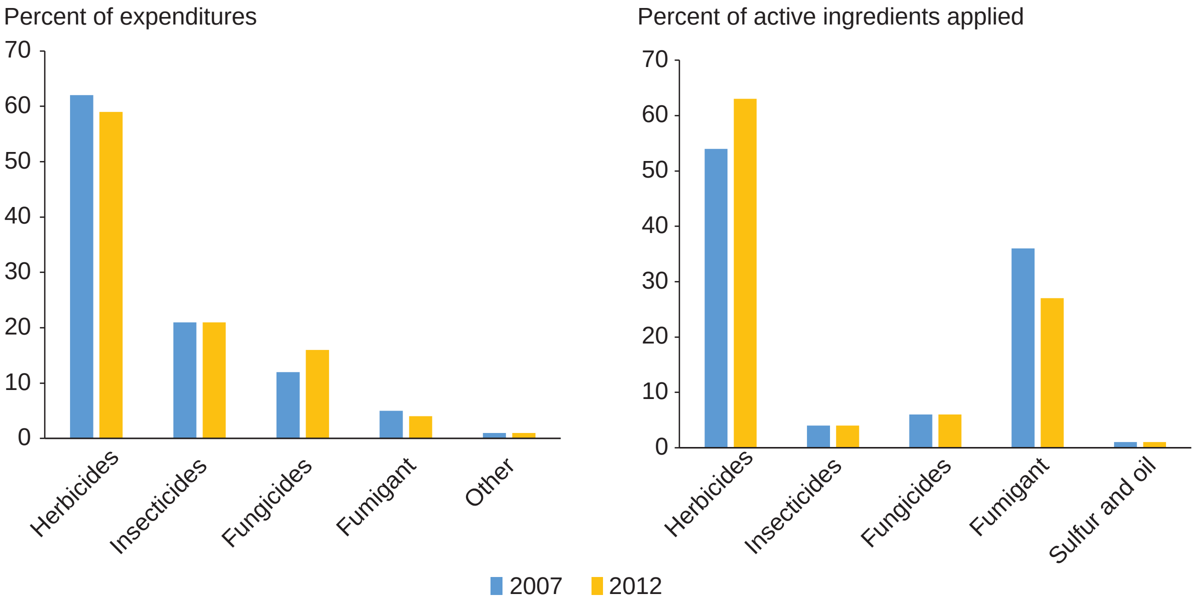
[1]Throughout this chapter, we aim to use the latest data available for the selected series at the time the report was prepared. Because of changes in the data sources and methodology used in EPA source documents, pesticide expenditures reported here for 2007 differ substantially from those reported for 2007 in the 2012 *Agricultural Resources and Environmental Indicators* report (USDA, Economic Research Service).

[2]Pesticide applications are often reported in pounds of active ingredient. The same quantities of different pesticides may have differing levels of toxicity, modes of action, target pests, and environmental impacts; hence, not all pounds are the same. Nonetheless, aggregated quantity data are widely reported and provide a useful base for tracking applications, while taking account of changes in pesticide attributes.

[3]These estimates do not include sulfur, oils, and unconventional pesticides such as biological or microbial pesticides.

Figure 2.8.1

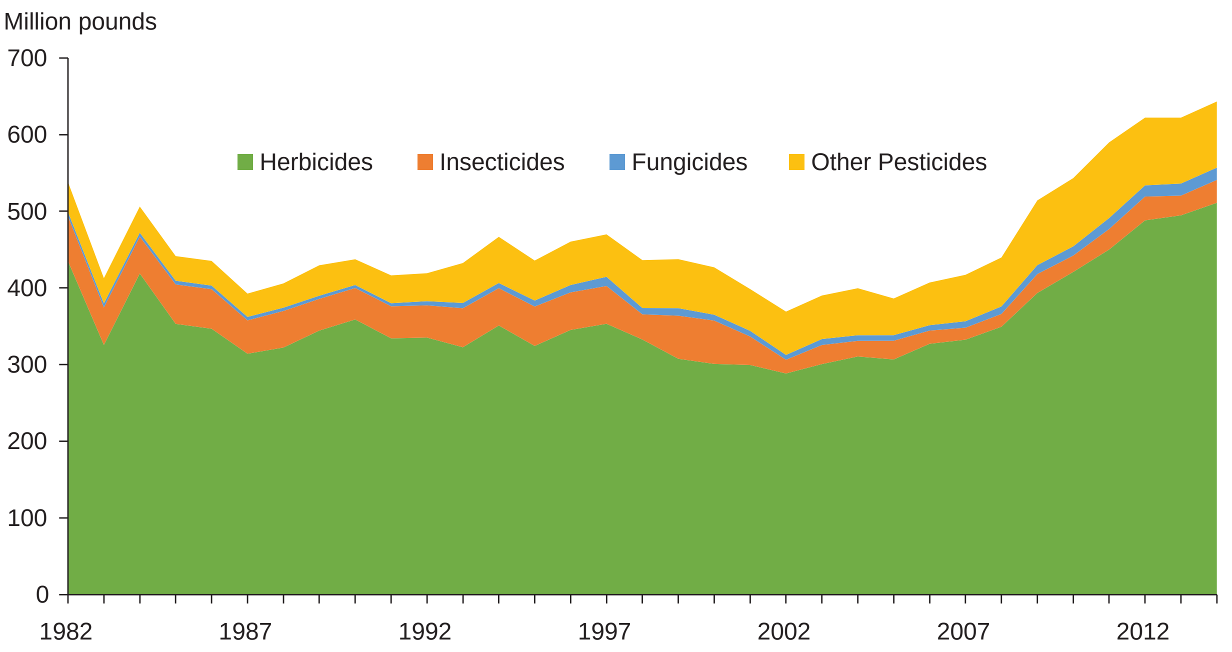
**Shares of pesticide expenditures and applications by chemical type in U.S. agriculture, 2007 and 2012**




Source: USDA, Economic Research Service using data from the U.S. Environmental Protection Agency, Pesticide Industry Sales and Usage: Market Estimates, 2006, 2007, and 2008-2012.

Figure 2.8.2

**Pounds of pesticide active ingredients applied to corn, cotton, fall potatoes, soybeans, and wheat, 1982-2014**

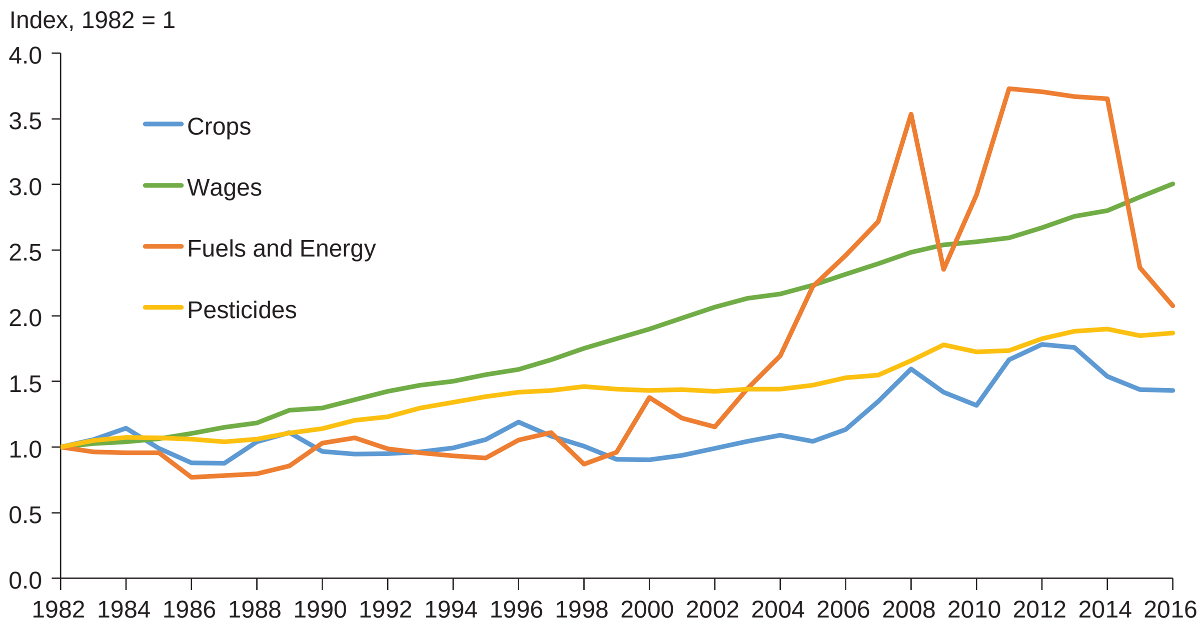



Source: USDA, Economic Research Service using data from Baker (2017) and Fernandez (2014).

Changes in pesticide use follow from several factors: changes in the mix of crops produced (with a substantial shift of acreage to corn and soybeans after 2000); the widespread adoption of genetically engineered crops, which led to reductions in insecticide use and changes in the types of herbicides used; the availability of new chemical compounds with lower application rates; boll-weevil eradication in cotton-producing States, which reduced insecticide use; and shifts in input prices, which encouraged greater pesticide use.[4] Between 1980 and 2016, pesticide prices rose by 87 percent while farm wages rose by 200 percent; the shifts in relative prices encouraged farmers to adopt practices that reduced the use of labor and increased the use of pesticides and equipment (figure 2.8.3).

Figure 2.8.3

**Price indexes for crops, wages, fuels/energy, and pesticides, 1982-2016**




Source: USDA, Economic Research Service using data from USDA, National Agricultural Statistics Service, Agricultural Statistics.

## Herbicide Trends

Herbicides are the dominant type of pesticide applied in the United States. Herbicide quantities applied to the five major crops trended downward between 1982 and 2002, from 435 to 288 million pounds, but then grew to 511 million pounds by 2014. In turn, the herbicide glyphosate accounted for a growing share of all herbicides used. In contrast, insecticide quantity has trended downward since 1982.

Herbicides can be grouped into several categories. In the 1960s through 1980s, the major herbicide classes were amides, anilines, carbamates, phenoxys, and triazines. Some of these "old-line" herbicides commonly used in U.S. crop production include 2,4-D, atrazine, and acetachlor. In the 1980s and 1990s, herbicides based on ALS inhibitors—and to a lesser extent Acetyl-CoA carboxylase (ACCase) and Protoporphyrinogen oxidase (PPO) inhibitors—were introduced. "New-line" herbicides commonly used in U.S. crop production include acifluorfen, clethodim, and glufosinate (see Osteen and Fernandez, 2016, for a more complete list). Last, glyphosate—first sold commercially in 1974—is considered new line, but is in a group of its own to reflect its relative importance.

[4]The cotton boll weevil (*Anthonomus grandis Boheman*) has been eradicated from all cotton-producing States, except for a part of Texas (USDA, APHIS, 2013). See also Southwest Farm Press (2017) for recent progress in the eradication program.

Major factors affecting overall herbicide use trends since 1980 include:

1. Changes in crop acreage, influenced by economic and policy factors;
2. The replacement of older compounds with newer ones that are applied at lower per-acre rates;
3. The adoption of genetically engineered crops since the mid-1990s (see chapter 2.7, "Biotechnology, Seed Use, and Pest Control for Major U.S. Crops"); and
4. Evolution of herbicide resistance in weeds.

## Changing Mix of Herbicide Types Used in the United States

Since new-line herbicides are generally applied at lower rates, their increasing use, together with declining crop acreages through the late 1980s, contributed to declines in aggregate herbicide quantities applied between 1982 and 2002 (Osteen and Fernandez, 2016). The year 1996 saw the introduction of corn, cotton, and soybean seeds that were genetically engineered to be tolerant of the broad-spectrum herbicide glyphosate, sold under the Roundup label. This allowed farmers to spray the herbicide on field after the crop emerged, thus easing weed management for farmers. Glyphosate was quite effective at controlling a wide range of weeds; it was less environmentally damaging than old-line herbicides; and the herbicide's price also fell sharply after it went off-patent in 2002. The expansion of corn, cotton, and soybean acres planted to glyphosate tolerant seeds accelerated rapidly, and led to the displacement of other herbicides by glyphosate. Glyphosate use in the U.S. agricultural sector increased sevenfold between 1995 (the year before glyphosate-tolerant seeds were introduced) and 2014.

Heavy reliance on a single mode of weed control encourages the spread of weeds that are resistant to that mode, as resistant individual weeds survive and propagate (Livingston et al., 2015; Owen, 2015). The heavy, and often exclusive, reliance on glyphosate in many areas led to the rapid emergence and spread of glyphosate-resistant weeds, but there is evidence that weeds are developing resistance to other herbicides as well (Heap, 2015; Owen, 2015).

Farmers responded to growing weed resistance by increasing their use of other old- and new-line herbicides, but also by increasing their application rates for glyphosate. (Peterson et al., 2018). From 2010 to 2014, glyphosate use increased by 41 million pounds, but use of old-line herbicides increased by 51 million pounds. By 2014, while glyphosate was still the largest-selling herbicide product, old-line herbicides as a group accounted for half of herbicide quantity applied. Application rates (for all herbicides) increased by 20 percent from 1.67 pounds per acre in 2010 to 1.92 pounds in 2014, reflecting more intensive use.

We can track the use of old-line herbicides, glyphosate, and other new line herbicides for the four major herbicide-using crops—corn, cotton, soybeans, and wheat. We illustrate the share of herbicide- treated acres receiving each kind of herbicide in figure 2.8.4 and the shares of each herbicide type in total herbicide applied (by weight) in figure 2.8.5. Finally, we track average application rates, per acre treated with herbicide, in figure 2.8.6.[5]

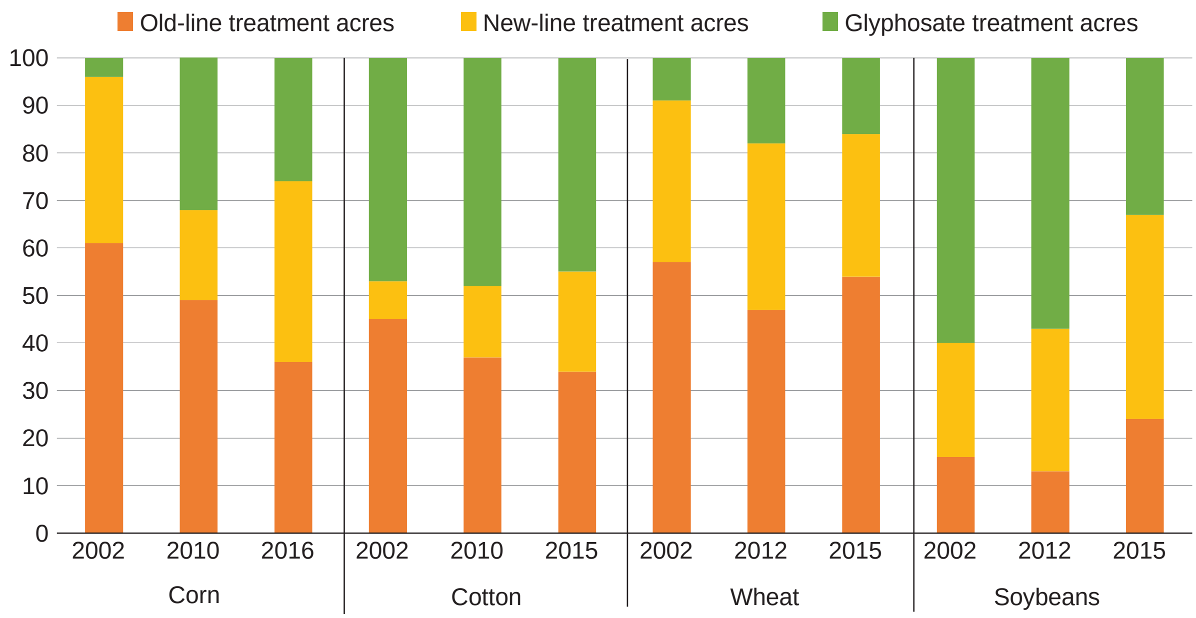
[5]Data on acre-treatments for figure 2.8.4 are drawn from USDA, National Agricultural Statistics Service data, while those in figures 2.8.5 and 2.8.6 are drawn from U.S. Geological Survey data. The dates of the most recent data available differ by source.

Several patterns stand out:

- Glyphosate was used more widely and intensively in soybeans than in corn, cotton, or wheat (figure 2.8.4 and figure 2.8.5).
- All four crops show a decline in the share of acres treated with glyphosate in recent years: after 2010 (corn and cotton) or 2012 (soybeans and wheat, figure 2.8.4).
- Looking at shares of herbicides applied by weight (fig. 2.8.5), the prevalence of glyphosate use increased slightly for corn, rose for wheat, and fell for cotton and soybeans in the most recent year for which data were available.
- Old-line herbicides increased their share of total pounds applied for both cotton and soybeans, stabilized in corn, and decreased in wheat (figure 2.8.5).
- Application rates increased persistently for each of the four crops after 2002 (figure 2.8.6).

Figure 2.8.4

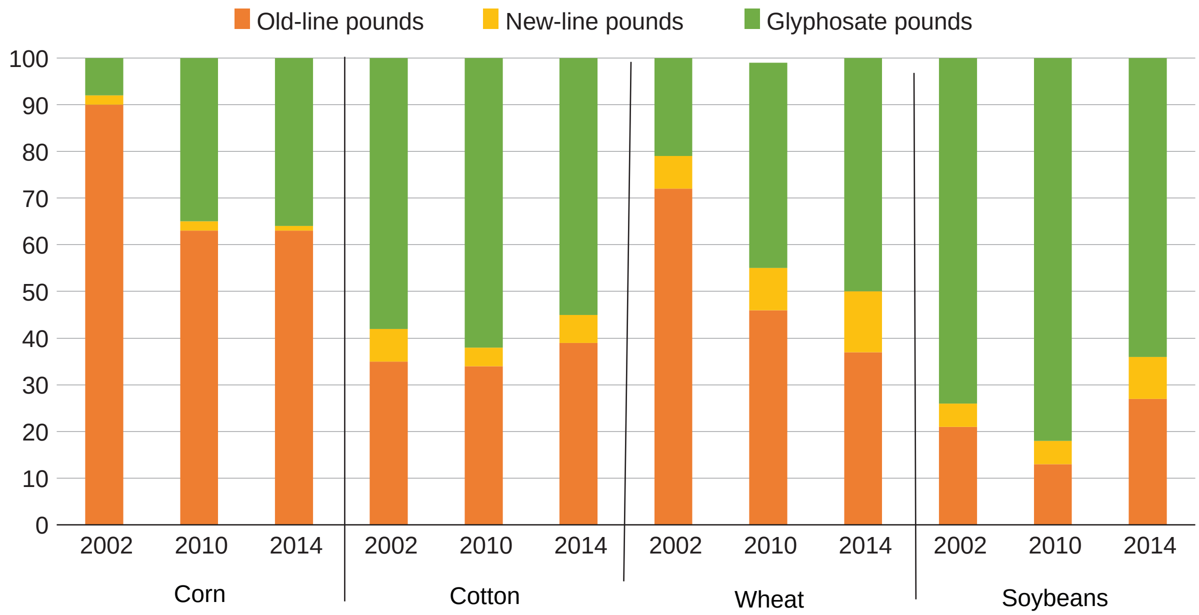
**Shares of herbicide type applied (old line/new line/glyphosate) on herbicide-treated acres, by crop and year, 2002-2016**




Note: Years displayed reflect years of survey data availability, which vary by crop. The final year of data displayed (2016 for corn, and 2015 for cotton, wheat, and soybeans) reflects the latest USDA NASS survey years for that crop. Old-line herbicides were in families first observed in the 1964, 1966, or 1971 surveys; glyphosate was first observed in the 1976 survey; and new-line herbicides were in families or modes of action (MOAs) first observed in the 1976 or later surveys (Fernandez and Osteen, 2016).
Source: USDA Economic Research Service using data from USDA, National Agricultural Statistics Service (NASS), Quick Stats.

Figure 2.8.5

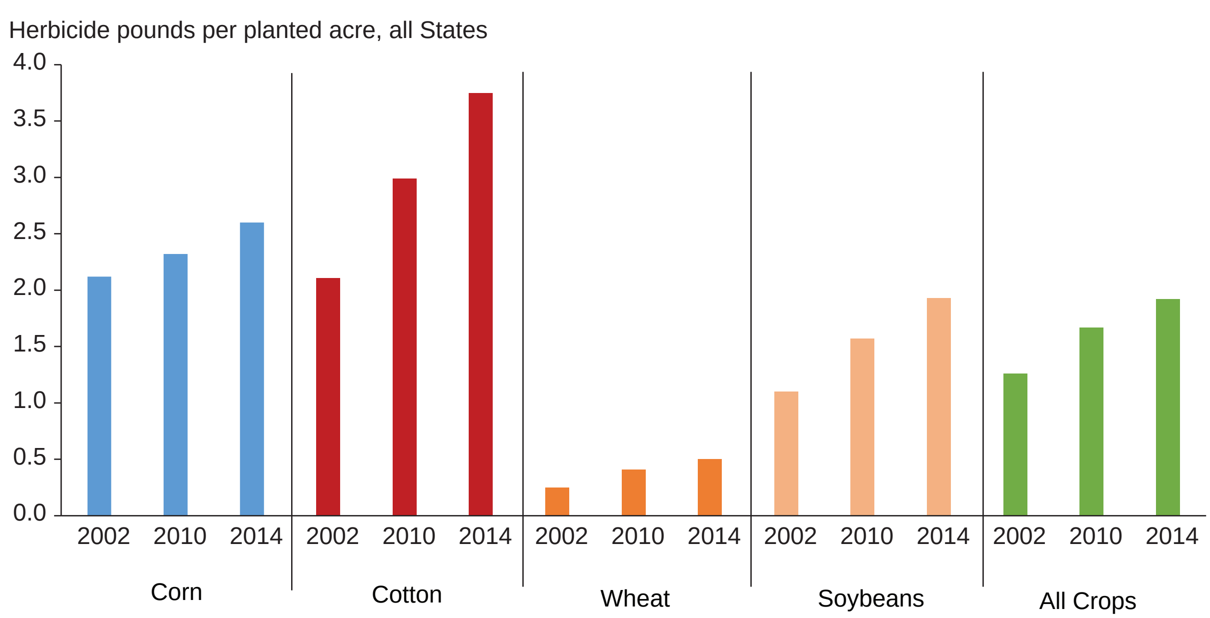
**Shares of herbicide type applied (old line/new line/glyphosate) by weight for four major crops, 2002-2014**




Note: Old-line herbicides were in families first observed in the 1964, 1966, or 1971 USDA NASS surveys; glyphosate was first observed in the 1976 USDA survey; and new-line herbicides were in families or modes of action (MOAs) first observed in the 1976 or later USDA surveys (Fernandez and Osteen, 2016).
Source: USDA, Economic Research Service using data from the U.S. Geological Survey (Baker, 2017).

Figure 2.8.6

**Herbicide application rates for four major crops and all crops, 2002-14**




Source: USDA, Economic Research Service using data from the U.S. Geological Survey (Baker, 2017).

## Summary

Herbicides account for the vast majority of pesticide applications by U.S. farmers. Patterns of herbicide use have shifted in recent years. Total application of herbicides has increased in the last decade, after showing little trend for nearly 25 years. The resurgence of old-line herbicides is evident as producers struggle with herbicide resistance in weeds caused by recurring use of the same chemicals, such as glyphosate (Arp, 2017). In short, herbicide-use patterns differ by crop, with variations in the mix of old-line and new-line (including glyphosate) herbicide use driven by weed resistance and other factors.

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# Chapter 2.9—Nutrient Management

Roberto Mosheim

- Commercial fertilizer consumption was about 22 million short tons in 2015, recovering from the 18-percent drop between 2008 and 2009.
- Since 1997, nitrogen recovery rates (the share of applied nutrient taken up by the harvested crop) on corn, winter wheat, and cotton have hovered around 70 percent, while recovery rates for phosphate have remained around 60 percent.
- The shares of planted acreage where application rates exceed 125 percent of the crop's agronomic need (a measure of nutrient overapplication) have decreased for both nitrogen and phosphate.

This chapter examines the key technological and economic drivers of plant nutrient consumption and trends in nutrient use efficiency.[1] There is a complex interaction between fertilizer use and subsequent benefits and costs. On the one hand, crop plants require inorganic nutrients such as nitrogen, potash, and phosphate for crop production. On the other hand, excessive application of nutrients can damage air and water resources through soil erosion, runoff, volatilization, and leaching (Ribaudo et al., 2011).

When fertilizer applications are warranted for crops, the application of excess nutrients can be reduced by implementing what USDA's Natural Resources Conservation Service[2] and The Fertilizer Institute promote as the 4Rs. The 4Rs direct farmers to apply nutrients using the right source of nutrients (matching fertilizer type to crop needs), at the right rate (matching amount of required fertilizer(s) to crop needs), at the right time (making nutrients available when crops need them most), and in the right place (applying nutrients where crops can use them) (The Fertilizer Institute, 2017). The 4Rs can increase profitability—by reducing fertilizer expenses and by better targeting its use to raise yields—and reduce the undesirable environmental impacts of excessive nutrient use.[3]

## Variability in the Use of Nutrients

Commercial fertilizer use surged from 7.46 million short tons[4] in 1960 to a peak of 23.68 million short tons in 1981 (figure 2.9.1). Total commercial fertilizer consumption of nitrogen, phosphate, and potash increased as more acres were devoted to high-yield crop varieties and as developed hybrids responded well to more intensive use of commercial fertilizer (EPA, 2017b).

Total applications of nitrogen, phosphate, and potash use on corn, soybeans, and wheat increased from 1964 to 1981 but declined for cotton. The expansion of total nutrient use through 1981 reflects expanded acreage (except cotton acreage, which fell slightly), increases in application rates, and a higher share of acres receiving fertilizer. This long expansion in fertilizer use ended in 1982. Since then, fertilizer use has

[1]Data sources include the most current data from USDA-ERS Fertilizer Use and Price data products, based on "Commercial Fertilizers, 2015" published in October 2018, and the latest commodity-specific Phase II surveys—corn, 2016; cotton, 2015; soybeans, 2012; and winter wheat, 2017.

[2]See, for example, USDA Natural Resources Conservation Service's (2013) Nutrient Management Practice Standard 590.

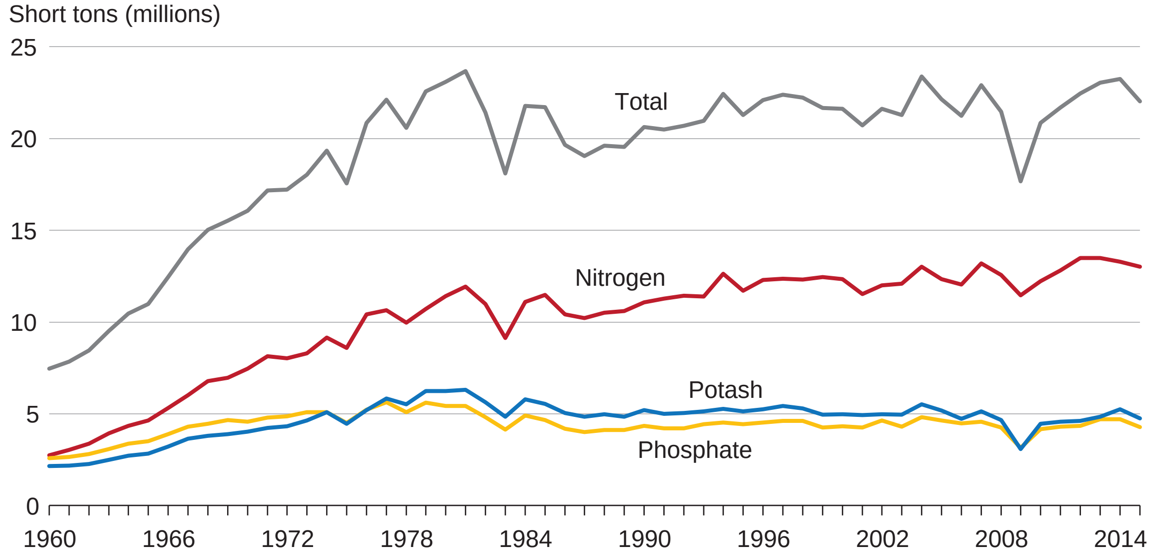
[3]The implementation of the 4Rs conforms with precision agriculture. For example, Schimmelpfennig (2016), Snyder (2016), and Bruulsema (2017) examine technologies such as global positioning system (GPS) mapping, grid or zone soil sampling, yield monitors, and variable-rate technology (VRT) that can improve nutrient use and reduce environmental risk (see chapter 2.11, "Precision Agriculture").

[4]One short ton = 2,000 pounds.

fluctuated over time in line with changes in cropping system implementation and fertilizer/crop prices, but has shown no persistent trend.

Figure 2.9.1

**Total nutrient use increased dramatically until 1981**




Note: 1 short ton equals 2,000 pounds.
Source: USDA, Economic Research Service using data from the Tennessee Valley Authority, Association of American Plant Food Control officials (2018).

Lower fertilizer prices generally meant increased fertilizer use until the energy crisis of 1973, when fertilizer prices jumped temporarily to their highest level ever. Still, nutrient use kept increasing (figure 2.9.2).[5] Commercial fertilizer prices slid until 2002, when they bottomed out at $247 per ton—historically, the lowest (inflation-adjusted) average fertilizer price for which data are available. Since 2002, fertilizer prices have fluctuated significantly, with no clear effect on fertilizer use.

Domestic fertilizer demand does not affect fertilizer price, but global events in energy markets do. For example, movements in key fertilizer feedstock prices like natural gas affect fertilizer prices and, in turn, demand. A key event, the global economic crisis of 2008/2009, put downward pressure on natural gas prices, which in turn reduced fertilizer prices. Fertilizer prices fell 18 percent from 2008 to 2009 (fig. 2.9.2) and fertilizer use dropped 14 percent because of reduced global incomes.[6] By 2015, fertilizer use and price were back to pre-crisis levels. Fertilizer prices have fallen relative to 2015, but nitrogen fertilizer prices appear to have stabilized thus far in 2018 (Schnitkey, 2017 and 2018).

[5]USDA-ERS constructed a price index for fertilizer using the prices (see USDA-NASS, *Agricultural Prices, 2017*) of anhydrous ammonia, urea 44-46 percent nitrogen, ammonium nitrate, sulfate of ammonium, and super-phosphate 44-46 percent phosphate. USDA-NASS stopped publishing these prices in 2015. The price data were deflated by the Consumer Price Index (2016 = 100).

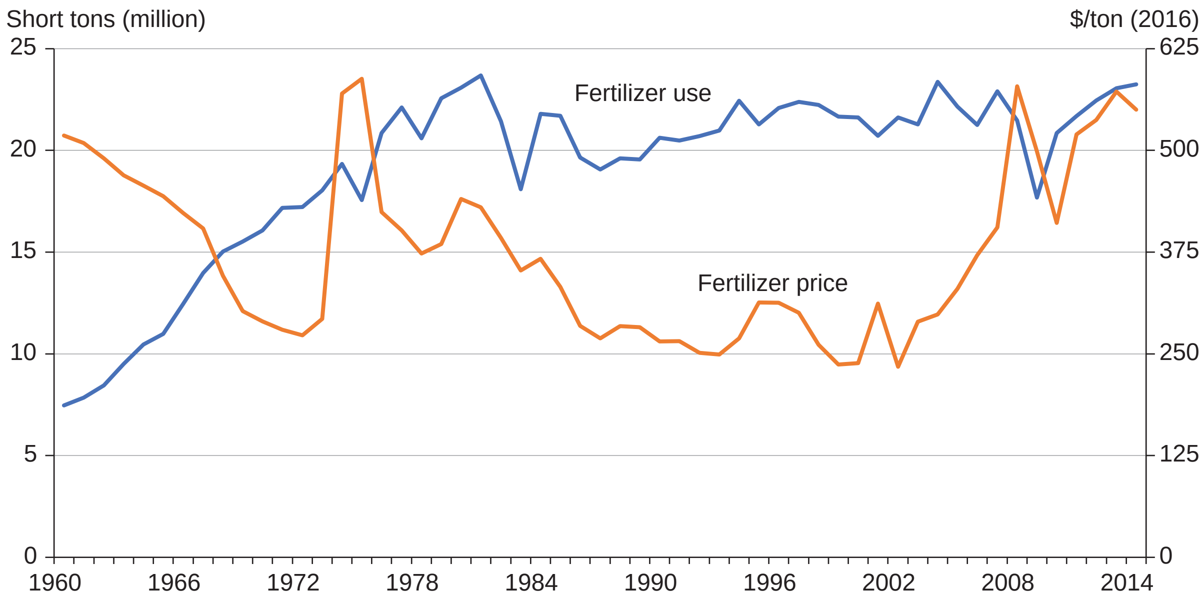
[6] Shane et al. (2009) document the effects of the 2008/2009 world economic crisis on U.S. agriculture.

An increase in natural gas production came after the ascendancy of horizontal drilling and hydraulic fracturing in the United States—in October 2011, hydraulically fractured wells became the predominant method for new United States oil and gas development (EIA, 2018). In turn, the increase in the supply of this crucial raw material in the manufacture of nitrogen fertilizer put downward pressure on fertilizer prices at the cost, however, of an increased risk of environmentally damaging drinking water resources (EPA, 2016).

The above interactions between fertilizer prices and quantity are important from an environmental perspective. For example, how responsive is fertilizer demand to movements in fertilizer price? The literature (Roberts and Heady, 1982; Yang and Shumway, 2015) finds that the sensitivity of fertilizer demand to fertilizer price is very small (within its historic price ranges). Meanwhile, domestic fertilizer prices are highly dependent on prices determined in the international market, including the price of natural gas, a crucial raw material in the manufacture of ammonia, which in turn is fundamental to inorganic nitrogen fertilizer. Weak demand response to price affects implementation of best practices in the application of fertilizer and influences policies designed to contain the environmental damage from the overapplication of nutrients.

Figure 2.9.2

**Fertilizer prices rose rapidly between 2002 and 2008**



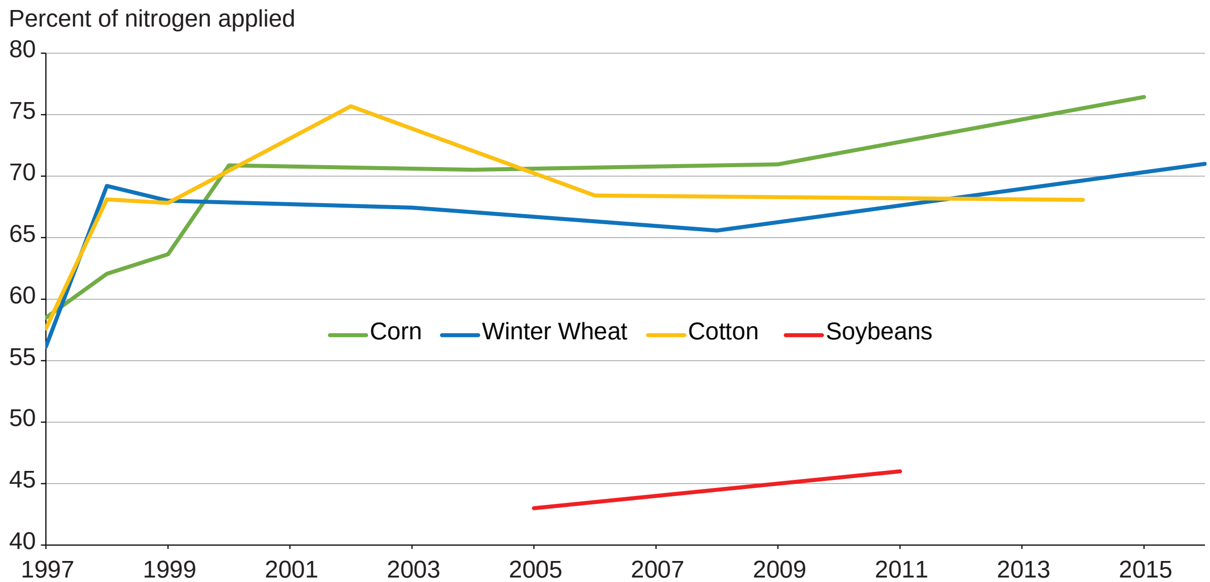

Note: Data adjusted for inflation to 2016 dollars using the Consumer Price Index. Fertilizer price and use moved in opposite directions until 1973. That is, between 1960 and 1973, fertilizer use expanded, partly in response to longrun price declines. Since 1973, movements in key fertilizer feedstock prices determined by global energy markets have been the main drivers of fertilizer prices. Fertilizer use is very insensitive to movements in fertilizer price. Prices increased 43 percent from 2007 to 2008, and use decreased 18 percent following the 2008-09 financial crisis.
Source: USDA, Economic Research Service analysis of data from the Tennessee Valley Authority, the Association of Plant Food Control Officials, and the Fertilizer Institute.

## Nutrient Recovery Rates Remain Constant for Most Crops

A well-designed nutrient management plan decreases nutrient expenses and lowers the environmental impact of nutrient use. Nutrient recovery is the ratio of the amount of nutrient in the harvested crop to the amount of nutrient applied (Huang and Beckman, 2012). Partial recovery occurs when the amount applied exceeds the amount that plants can absorb, resulting in environmental loss. The partial recovery index varies between 0 and 100, with 0 being the least efficient and 100 being the most efficient use of applied nutrients. Figures 2.9.3 and 2.9.4 show nitrogen and phosphate recovery ratios for corn, winter wheat, cotton and soybeans.[7] For corn, nitrogen efficiency increased from 58 percent in 1997 to 76 percent in 2015; for winter wheat, it increased from 56 percent in 1997 to 71 percent in 2016; for cotton, it increased from 58 percent in 1997 to 68 percent in 2014; and for soybeans it increased from 43 percent to 46 percent between 2005 and 2011.[8] Phosphate recovery increased from 60 percent in 1997 to 65 percent in 2015 for corn, but decreased from 64 percent (1997) to 60 percent (2016) for winter wheat. For cotton, phosphorus recovery increased from 58 percent in 1997 to 66 percent in 2014, with much variability in between. Phosphate recovery for soybeans fell from 74 percent in 2005 to 58 percent in 2011. This last result, however, is based on only 2 years of observations. Nutrient use efficiency increases can be tied to the improved varieties of crops being grown—ones that have been bred for higher nutrient use efficiencies—as well as to improved crop management practices that enable more efficient uptake of the applied nutrients (e.g., more farmers are following the 4Rs).

Figure 2.9.3

**Crop's nitrogen recovery rates**




Source: USDA, Economic Research Service and National Agricultural Statistics Service, Agricultural Resource Management Survey (ARMS), Financial and Crop Production Practices.

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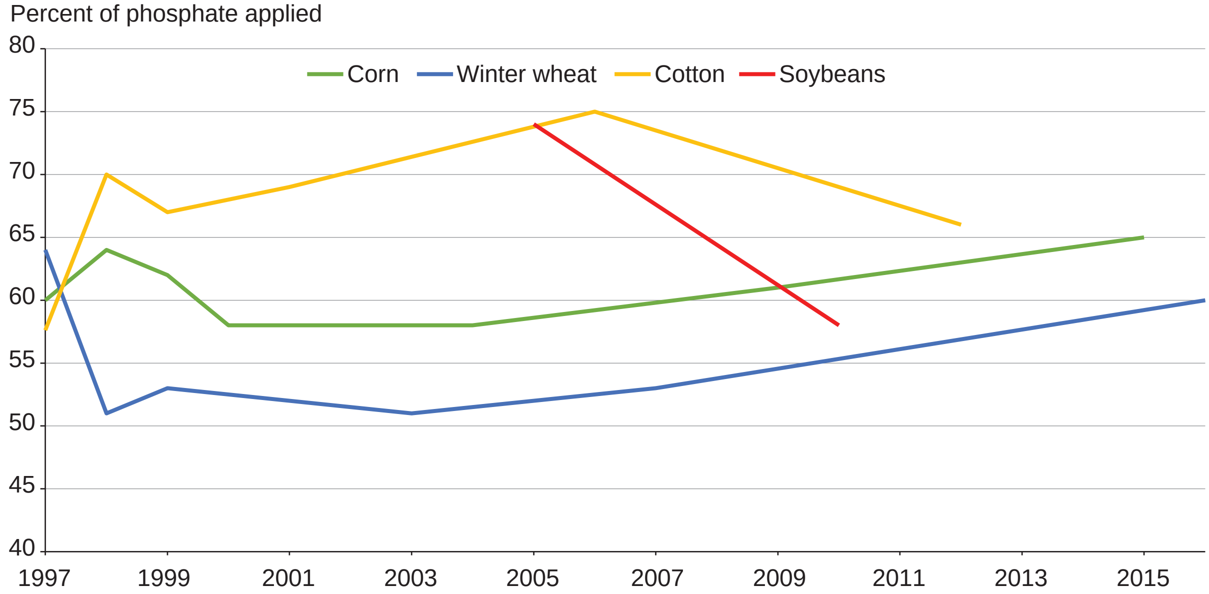
[7]Nutrients employed in these crops represented about 60 percent of the total amount of nutrients consumed in the United States. Available data were employed to generate comparable variables across time to generate meaningful nutrient trends. Also, 2000 was the last year when nutrient use data were collected for corn, soybeans, cotton, and wheat at the same time. Winter wheat production is about 10 percent of total wheat production.

[8]Mourtzinis et al. (2018) conclude that nitrogen (N) management decisions have a measurable, but small, effect on soybean yield and that given the growing pressure for increasing food production, it is imperative to further examine all soybean N decisions (application method, timing, and rate) in terms of environmental and cropping system aspects.

Figure 2.9.4
**Crop's phosphate recovery rates**




Source: USDA, Economic Research Service and National Agricultural Statistics Service, Agricultural Resource Management Survey (ARMS), Financial and Crop Production Practices.

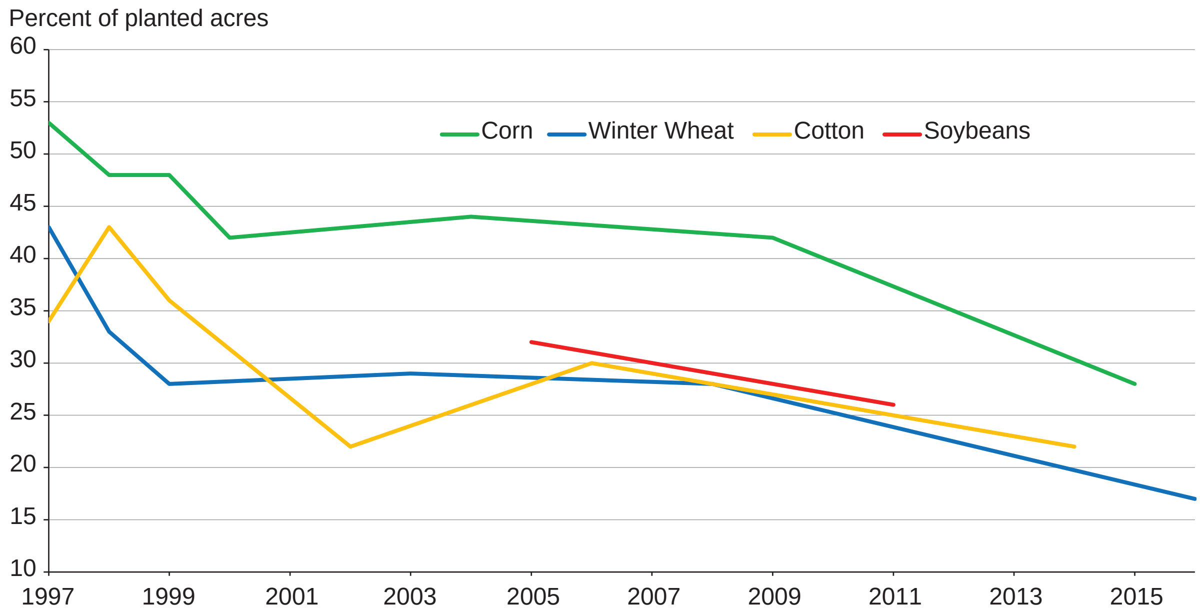
## Farmers Are Reducing the Share of Planted Acres With Excess Nutrient Use

For corn, the share of planted acres with excess nitrogen (above 125 percent of the crop's needs) decreased from 53 percent in 1997 to 28 percent in 2015 (fig. 2.9.5). For cotton, the share fell from 34 to 22 percent (2014). The share of soybean acres with excess nitrogen fell from 32 percent (2005) to 26 percent (2011); the share for winter wheat shows a decline from 43 percent (1997) to 17 percent (2016). The downward trend in share of acres with excess phosphate is pronounced, with a decline from 44 to 28 percent for corn and from 45 to 29 percent for cotton, but an increase from 33 to 41 percent for winter wheat and 31 to 33 percent for soybeans (fig. 2.9.6).

Farmers have mostly increased nutrient recovery rates across crops and have reduced the amount of land that uses excess nutrients. These efforts, in turn, have lowered the variability of adverse environmental outcomes across farmers. Empirical studies of environmental performance of nutrients in agriculture indicate that input combinations and the technology with which they are applied are factors that significantly affect environmental efficiency and productivity (Coelli et al., 2007). Moreover, practices such as crop rotation, use of precision agriculture tools, and monitoring nutrient uptake levels can help farmers boost production without increasing nutrient applications.

Figure 2.9.5

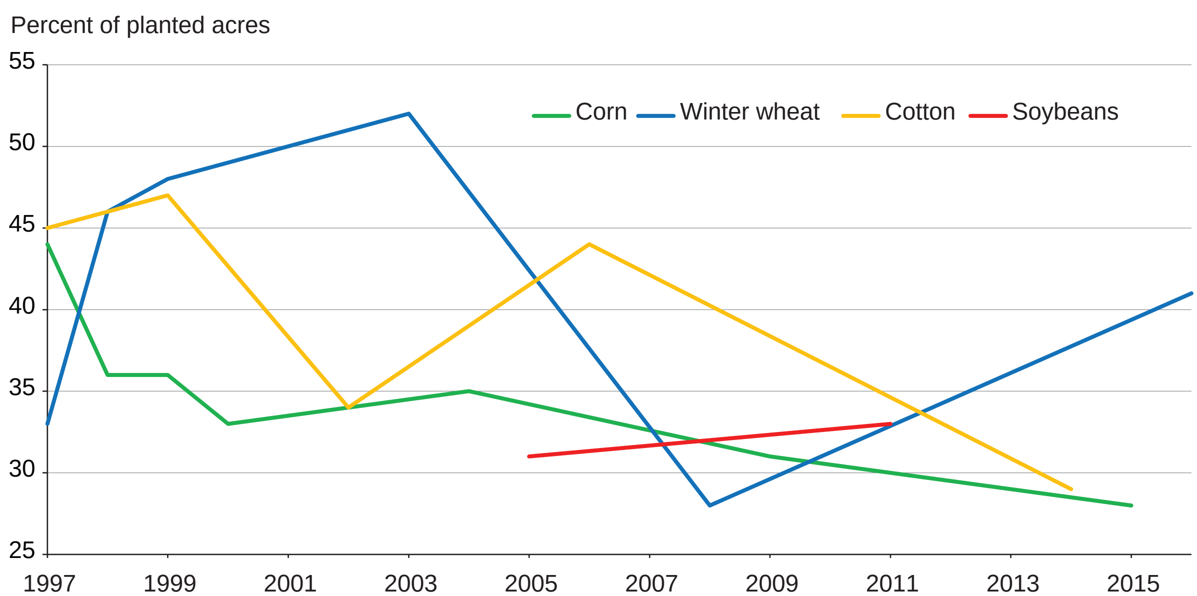
**Planted acres receiving nitrogen above 125 percent of crop's agronomic need**




Source: USDA, Economic Research Service and National Agricultural Statistics Service, Agricultural Resource Management Survey (ARMS), Financial and Crop Production Practices.

Figure 2.9.6

**Planted acres receiving phosphate above 125 percent of crop's agronomic need**




Source: USDA, Economic Research Service and National Agricultural Statistics Service, Agricultural Resource Management Survey (ARMS), Financial and Crop Production Practices.

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# Chapter 2.10—U.S. Irrigated Agriculture: Farm Structure, Technology, and Conservation

Glenn Schaible and Marcel Aillery

- Irrigated farms accounted for approximately 39 percent of U.S. farm sales for crop and livestock products and 50 percent of U.S. crop sales in 2012. Irrigation's importance is significantly higher in the more arid Western States, where 72 percent of U.S. irrigated acres were located and where irrigated farms accounted for nearly 60 percent of the region's farm sales and more than 70 percent of regional crop sales.

- Most U.S. irrigated farms (64 percent) were low-sales farms (under $150,000 in annual farm sales); however, large-scale farms ($1,000,000 or more) accounted for 60 percent of irrigated acres, 62 percent of farm water applied, and 79 percent of irrigated farm sales. Per-farm sales in the United States averaged $514,400 for irrigated farms and $133,600 for dryland-only farms.

- While irrigated agriculture has become more water-use efficient over time, future irrigation efficiency gains will depend increasingly on adoption of improved onfarm water-management practices in combination with high-efficiency irrigation application systems.

Irrigated agriculture relies heavily on the Nation's water resources to provide an important contribution to the U.S. agricultural economy. Irrigation is the largest use of U.S. freshwater withdrawals (42 percent) and, historically, accounts for the largest share of the Nation's consumptive water use (some 80+ percent) (USGS, 2018, 1998). Rising water demands and heightened water scarcity are likely to intensify pressures on agricultural water supplies. Technological change has driven an increase in agricultural water-use efficiency, and continued investment in water conservation across farms is expected to further increase efficiency gains, with potential benefits for farm-level returns, drought resilience, and water quality.

### Defining Water Use

The U.S. Geological Survey estimates water withdrawals, or the quantity of water withdrawn from a water source (e.g., a river, lake, or aquifer) by U.S. economic sector (USGS, 2018). USDA's Farm and Ranch Irrigation Survey (FRIS) reports onfarm applied water use, based on producer estimates of the quantity of water applied to the field for a particular crop and onfarm irrigation application system (USDA, 2014b). Crop consumptive water-use refers to the quantity of water actually consumed (taken up) by the crop over its various growth stages for plant retention and evapotranspiration. Withdrawal estimates generally include conveyance losses from the water source, while estimates of field water applied do not. Consumptive-use estimates, as compared to crop consumptive use, may or may not account for associated system efficiency losses (e.g., evaporation, deep percolation, and runoff) and salt-leaching requirements, which can vary for a given crop, location, and irrigation system. Which estimate to use and how to use it are important in clarifying discussions of water use and policy.

## Significance of Irrigation to U.S. Agriculture

Irrigated agriculture contributes significantly to the value of U.S. agricultural production. According to the 2012 Census of Agriculture, irrigated farms—representing just 14 percent of all U.S. farms—accounted for 38.6 percent of U.S. farm sales ($152.4 billion) and about 50 percent of U.S. crop sales ($106.3 billion), even though only 28 percent of harvested cropland is irrigated (table 2.10.1).

Table 2.10.1

**Market sales ($ billion) of U.S. farms, total and by region, 2012**

| | 17 Western States | 31 Eastern States | All U.S. |
|---|---|---|---|
| Irrigated farms | | | |
| Crop sales | 68.8 | 37.0 | 106.3 |
| All farm sales (including livestock) | 106.9 | 45.1 | 152.4 |
| All farms | | | |
| Crop sales | 95.7 | 116.1 | 212.4 |
| All farm sales (including livestock) | 182.2 | 211.8 | 394.6 |

Note: "All U.S." includes 17 Western States, 31 Eastern States, Alaska, and Hawaii.
Source: USDA, Economic Research Service using data from USDA, National Agricultural Statistics Service, 2012 Census of Agriculture (USDA, 2014a).

Roughly 56 million acres—or 7.6 percent of all U.S. cropland and pastureland—were irrigated in 2012. Among major U.S. field crops, irrigated acreage shares were highest for cotton (40.6 percent) and alfalfa hay (34.8 percent), followed by corn (14.7 percent), sorghum (12.2 percent), soybeans (9.4 percent), and wheat (6.9 percent). Irrigation is used on 36 percent of the acres in high-value specialty crops—fruits, vegetables, berries, and nuts—and also supports the livestock and poultry sectors through irrigated production of animal forage and feed crops. Much of the U.S. irrigated area is concentrated in the 17 Western States,[1] which accounted for 72 percent of U.S. irrigated acreage and nearly 70 percent of farm sales from all U.S. irrigated farms in 2012. In the West alone, irrigated farms generated nearly 60 percent of the region's total farm sales and more than 70 percent of regional crop sales.

Horticulture crops generally include floriculture and bedding crops, propagative materials, mushroom crops, nursery crops, and sod. Many of these crops, as well as fruits and vegetables, are often grown in greenhouses (e.g., as horticultural crops under protection). Irrigated horticulture farms accounted for $16.5 billion in U.S. farm sales in 2012, representing about 12.1 percent of farm sales for all irrigated farms. Farm sales from irrigated horticulture farms are concentrated largely in California (20.2 percent of U.S. irrigated horticulture farm sales in 2012), Florida (11.9 percent), Texas (6.3 percent), Oregon (5.5 percent), and North Carolina (4.6 percent).[2]

[1]Washington, Oregon, California, Idaho, Nevada, Arizona, Montana, Wyoming, Colorado, Utah, New Mexico, North Dakota, South Dakota, Nebraska, Kansas, Oklahoma, and Texas.

[2]Irrigated farms with horticultural crops grown under protection (e.g., greenhouses) account for the majority (73.3 percent) of sales from all irrigated horticulture farms.

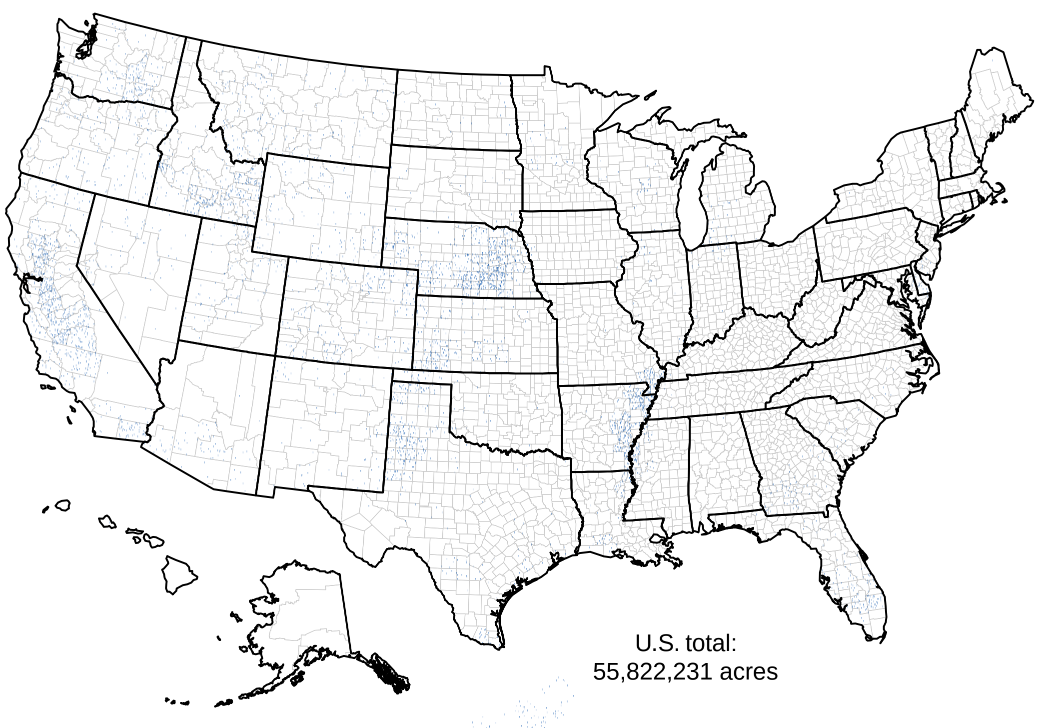
## Location of U.S. Crop Irrigation

Agricultural census data illustrate the distribution of U.S. irrigated agriculture in 2012 (fig. 2.10.1), as well as the change in irrigated acreage over time. From 2002 to 2007, U.S. irrigated acreage expanded by nearly 1.3 million acres (2 percent), with Nebraska accounting for 72 percent of the increase. Most of the remaining area expansion occurred in the Mississippi Delta and Southeast regions (primarily Arkansas, Mississippi, and Georgia). From 2007 to 2012, irrigated area declined by nearly 0.8 million acres nationally, with acreage contractions exceeding 10 percent in Texas, Colorado, Oregon, New Mexico, and Oklahoma, due in part to drought conditions that contributed to water-supply shortages. From 2007 to 2012, irrigated area in the Eastern States expanded by roughly 8 percent.

The five leading irrigation States in 2012 accounted for slightly more than half of irrigated acres nationally. Nebraska had the largest share of U.S. irrigated area with 8.3 million acres (15.1 percent of the national total), followed by California at 7.9 million acres, Arkansas at 4.8 million acres, Texas at 4.5 million acres, and Idaho at 3.5 million acres.

Fig. 2.10.1

**Acres of irrigated land, 2012**




Note: Each dot equals 10,000 acres.
Source: USDA, Economic Research Service using data from USDA, National Agricultural Statistics Service, 2012 Census of Agriculture.

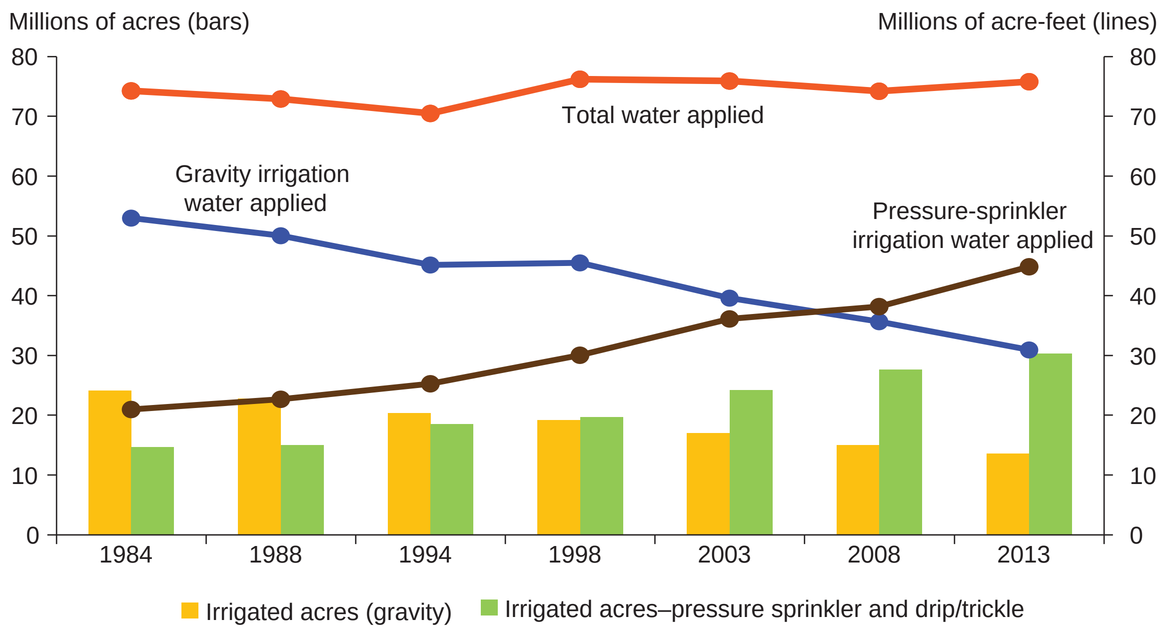
## Water Use by Type of Agriculture and Trends by Irrigation Technology

Based on USDA's most recent survey of irrigated farms—the 2013 Farm and Ranch Irrigation Survey (FRIS)—U.S. irrigated farms applied 88.5 million acre-feet (maf) of water in 2013 (USDA, 2014b). The vast share of water used for agriculture is associated with irrigation water applied to field-crop and specialty-crop production on open fields, accounting for roughly 98.0 percent of the U.S. total.[3]

Total farm water applied has been relatively stable over time for the 17 Western States, ranging from about 74.3 maf in 1984 to 75.8 maf in 2013 (fig. 2.10.2). Estimated irrigated acres in the West have also been relatively stable, ranging from about 39.1 to 39.6 million acres during the same time period. While the aggregate average annual rate of applied water has held fairly constant (at about 1.9 acre-feet (af) per acre), dynamic factors influencing agricultural water demand—including changes in irrigated area and cropping patterns, higher crop yield and water consumptive use, shifts in withdrawals by water source, and rates of irrigation technology adoption—have varied across the West.

Figure 2.10.2

**Trends in irrigated acres and applied water use, 17 Western States 1984-2013**




Note: Water-use information from USDA's FRIS reports onfarm water applied, not withdrawals. Also, the area tracked includes only acres irrigated in the open. It excludes area (square-feet) under protection on horticulture operations.
Source: USDA, Economic Research Service using USDA, National Agricultural Statistics Service 1984, 1988, 1994, 1998, 2003, 2008, and 2013, Farm and Ranch Irrigation Survey (FRIS) data.

[3]Horticulture crops accounted for the remaining 2.0 percent of agricultural water use applied. Horticulture crops produced under protection, covering 1.4 billion square feet (equivalent to about 32,000 acres), used approximately 54,400 acre-feet of water, or just 0.06 percent of U.S. irrigation water use in 2013.

The shift from gravity-flow to pressurized-sprinkler application systems has been particularly significant. In general, annual applied water rates under pressurized-sprinkler systems are considerably lower than under gravity-flow systems (1.2 af/acre compared with 2.3 af/acre across the West in 2013). In 1984, 62 percent of irrigated acres relied on gravity systems, compared with just 34 percent of irrigated acres in 2013. Over the same period, the share of Western irrigated acres using pressure-sprinkler (including drip/trickle) irrigation systems rose from 37 to 76 percent (with some acres irrigated with both systems). The corresponding shift in Western applied water use by irrigation technology has been more dramatic as water scarcity has intensified. Water applied using gravity systems steadily declined from 71 percent to 41 percent of total applied water, with a corresponding increase in water applied with pressure-sprinkler systems. While the trend from gravity to sprinkler systems is observed over the entire 30-year period, the decline in gravity systems and concurrent expansion in sprinkler area and water use accelerated after the late 1990s. The extent and timing of these shifts, however, vary significantly across the Western States.

## Farm-Size Characteristics of Irrigated Agriculture

Most irrigated farms are low-sales farm operations with under $150,000 in annual farm sales. Of the 229,200 irrigated farms across the United States in 2013, 64 percent were low-sales farms.[4] However, large-scale farms—those with $1,000,000 or more in farm sales—occupy most of the irrigated acres and use most of the applied irrigation water. These farms account for 60 percent of U.S. irrigated area and 61.5 percent of farm water applied. For the Western States, the largest irrigated farms—those with farm sales of $350,000 or more (22 percent of irrigated farms)—account for nearly 80 percent of the region's applied irrigation water.

Large-scale irrigated farms account for most of the value (79 percent) of farm production sales from irrigated farms, reflecting both their larger acreages and more extensive investment in irrigation systems. Low- and moderate-sales irrigated farms, which account for 75-78 percent of all irrigated farms, accounted for just 7.7 percent of irrigated farm production sales. For all irrigated farms, the average farm sales ($ per farm) across the United States in 2012 was nearly four times that of farms not irrigating: $514,400 per irrigated farm, compared to $133,600 per nonirrigated farm.[5]

## Importance of Conservation for Irrigated Agriculture

Many forces such as population and economic growth, expansion of the U.S. energy sector, Native American water-right claims, and water quality and ecosystem restoration initiatives—are driving increased demands for water resources across the country. On the supply side, continued overdraft of groundwater aquifers (where withdrawals exceed annual hydrologic recharge) is expected to reduce the future availability of groundwater supplies for irrigation use in important agricultural regions. While the precise effect of climate change on water resources is uncertain, climate change is projected to shrink surface-water supplies in much of the West through reduced snowpack, shifting precipitation patterns, and higher evaporative losses. At the same time, warming temperatures are expected to contribute to

[4]Farm-size characteristics of irrigated farms were summarized based on USDA data from the 2013 Farm and Ranch Irrigation Survey (FRIS). Four farm-size classes were examined based on the "total farm sales (FS)" variable acquired from the 2012 Census of Agriculture: (1) *low-sales farms* (FS < $150,000); (2) *moderate-sales farms* (FS $150,000 to < $350,000); (3) *mid-size farms* (FS $350,000 to < $1,000,000); and (4) *large-scale farms* (FS $1,000,000 and more). See chapter 1.1, "Farm Numbers and Size," for characteristics of all farms (irrigated plus non-irrigated).

[5]For more detailed information on U.S. irrigated agriculture characteristics by farm-size class, see the ERS data product "Irrigated Agriculture in the United States."

increased water demands due to rising evapotranspiration rates and potentially greater frequency and severity of drought (Georgakakos et al., 2014). In most river basins of the Western States, surface-water supplies are fully appropriated, and opportunities for large-scale water-supply development are limited. These trends, taken together, are expected to intensify competition for existing water allocations, heightening the importance of water conservation for a sustainable irrigated agriculture sector.

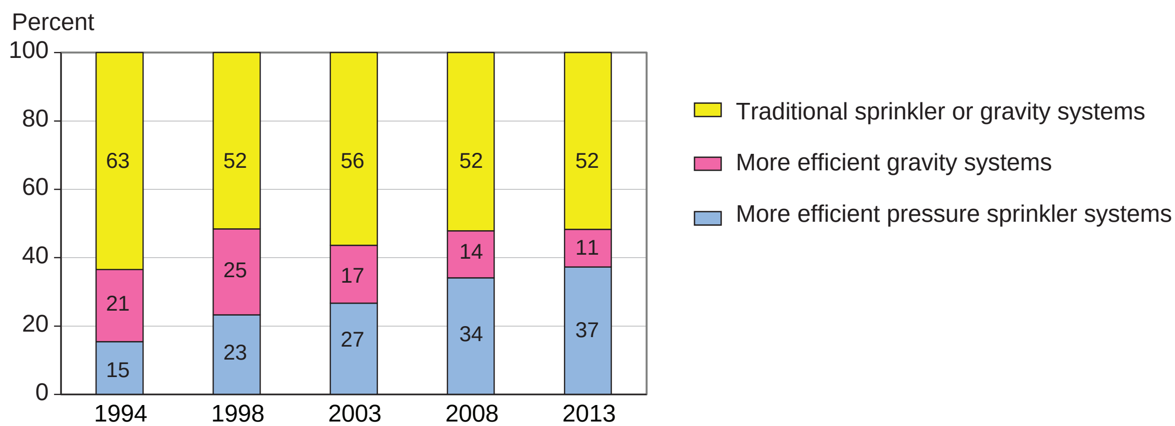
## Onfarm Irrigation Efficiency: Benefits and Opportunities for Improvement

Improvements in physical irrigation systems and water management have helped to increase onfarm irrigation efficiency, or the share of applied water that is beneficially used for crop production. Gains in water-use efficiency provide various farm-level benefits, including improved crop yields and potential savings in water costs and other applied inputs. Improved water-use efficiencies, particularly when implemented in concert with watershed-scale conservation measures that limit expansion in irrigated area or reduce water withdrawals, can provide off-farm benefits as well, including fish and wildlife habitat, and reduced ecosystem and human health risks associated with environmental degradation.

While substantial technological innovation has already occurred in U.S. irrigated agriculture, additional water-use efficiency gains are achievable (Schaible and Aillery, 2016; see also chapter 3.16, “Farm-Level Adaptation to Drought Risk”).[6] Based on FRIS results, much of the growth in high-efficiency systems reflects the expansion in pressurized sprinklers and micro-irrigation systems (fig. 2.10.3). The share of acres using more efficient gravity systems peaked in the late 1990s, but then declined as farmers increasingly turned to the even more efficient pressure-sprinkler/micro-spray and drip systems. However, more than half of irrigated cropland acres in the West continue to be irrigated with more traditional application systems.

Figure 2.10.3

**Trends in the shares of acres irrigated with more efficient irrigation systems, by system type, for the 17 Western States, 1994-2013**




Note: **Efficient gravity irrigation** includes furrow irrigated acres using above- or below-ground pipe, or a lined open-ditch field water-delivery system, plus acres in flood irrigation (between borders or within basins) on farms using laser-leveling and pipe or lined open-ditch field water-delivery systems. **Efficient pressure-sprinkler irrigation** includes acres using either drip/trickle and low-flow micro systems or lower pressure-sprinkler systems [pressure per square-inch (PSI) < 30]. **Traditional irrigation** includes all remaining irrigated acres associated with traditional irrigation systems, including less water-use efficient gravity and sprinkler systems.
Source: USDA, Economic Research Service, using data from USDA’s National Agricultural Statistics Service Farm and Ranch Irrigation Surveys (FRIS) for 1994, 1998, 2003, 2008, and 2013.

[6]To assess shifts in relative irrigation efficiency over time, Schaible and Aillery (2016) characterize irrigation systems as either “traditional” or “efficient” depending on acreage by irrigation application system and their components reported in the FRIS for both gravity and pressurized systems.

FRIS data also indicate the potential for increased irrigation efficiency through more extensive use of onfarm water-management practices that improve the rate and timing of applied water. Fewer than 10 percent of irrigators make use of soil- or plant-moisture sensing devices or commercial irrigation scheduling services, while fewer than 2 percent use computer-based crop-growth simulation models to determine irrigation requirements based on consumptive-use needs by crop-growth stage under local weather conditions.

## Irrigation Investments and Continued Agricultural Water Conservation

Irrigators annually make significant capital investments in onfarm irrigation equipment and infrastructure—$2.6 billion in 2013 (72 percent in the West), with the large majority (90 percent) of these investments financed privately. Farms receiving public financial assistance for irrigation investments through USDA's Environmental Quality Incentives Program (EQIP) represent fewer than 5 percent of all irrigated farms reporting irrigation investments.

Further improvements in farm water conservation remain an important USDA farm policy goal (USDA, 2018). Through improved irrigation production systems that combine investments in irrigation technology with innovative water-management practices (e.g., a low-pressure sprinkler system with use of advanced sensor technologies), producers are better able to maximize the efficiency of their irrigation systems. Potential for real water savings at the watershed scale will depend on reduced system losses, the disposition of those losses (e.g., evaporation versus recharge), and as necessary, managed reductions in consumptive water use under more highly efficient systems. Institutional measures—such as tiered water pricing, withdrawal restrictions, water markets, conserved water rights, and instream flow requirements—may further incentivize investments in irrigation efficiency for farm-level water conservation or environmental quality protection.

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# Chapter 2.11—Precision Agriculture

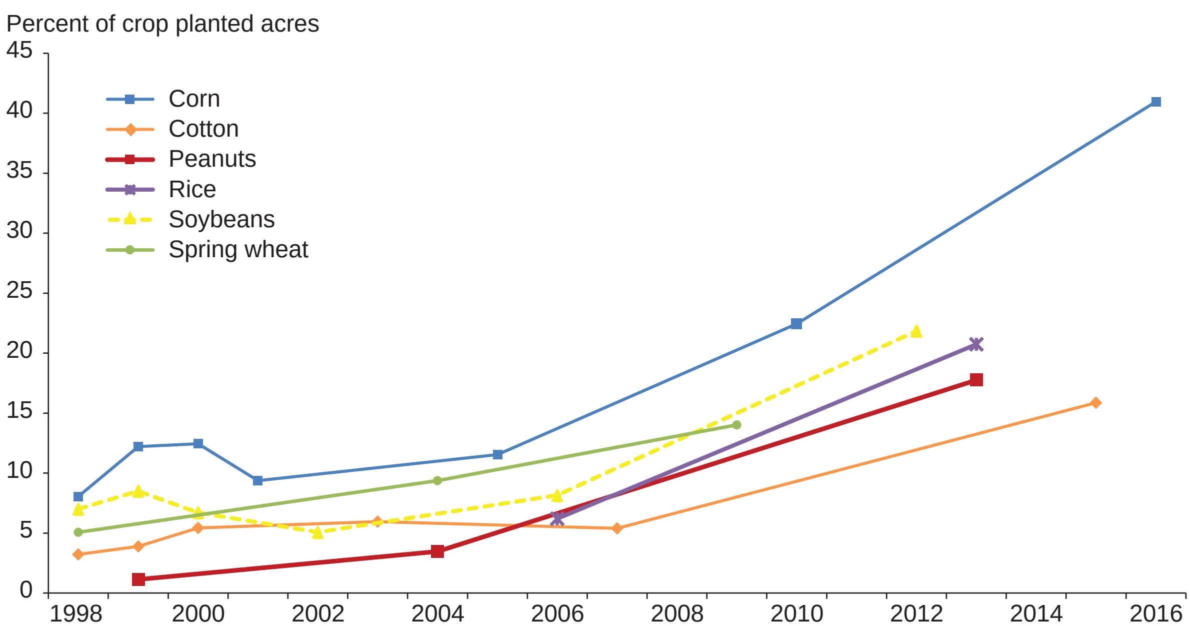
David Schimmelpfennig

- Precision agriculture allows farmers to save on seed, fertilizer, and pesticide costs; increase yields in certain situations; and be better stewards of farm resources. By 2016, 15-40 percent of U.S. farms used variable-rate application equipment, which adjusts input application rates depending on field conditions.
- Labor-saving self-steering guidance systems for tractors and combines were the most popular precision agriculture technology, reaching 50-60 percent of farm planted acres growing corn, peanuts, rice, and spring wheat.
- Precision technologies are associated with increased use of soil conservation tillage, erosion reduction, and nutrient control practices.

Precision agriculture (PrecAg) enables extremely localized crop production management through a number of different technologies. The most popular technologies—as identified in the USDA's Agricultural Resource Management Survey (ARMS, conducted by USDA's Economic Research Service and National Agricultural Statistics Service) between the late 1990s and 2016—are tractor guidance systems that use a global positioning system (GPS), GPS yield and soil mapping, and variable-rate input technology (VRT) applications. These three technologies help farms gather information on current state-of-field conditions and to then adjust production practices. VRT instructs machinery and field operation equipment—such as sprayers and seeders—to automatically control input flow rates. This allows farmers to manage their seed, fertilizer, and pesticide applications foot by foot rather than field by field—and to do so on a per application basis. The more variable infield growing conditions are, both in time and space, the more valuable VRT is to farmers.

Figure 2.11.1

**Adoption of variable-rate technology (VRT) by crop, 1998-2016**

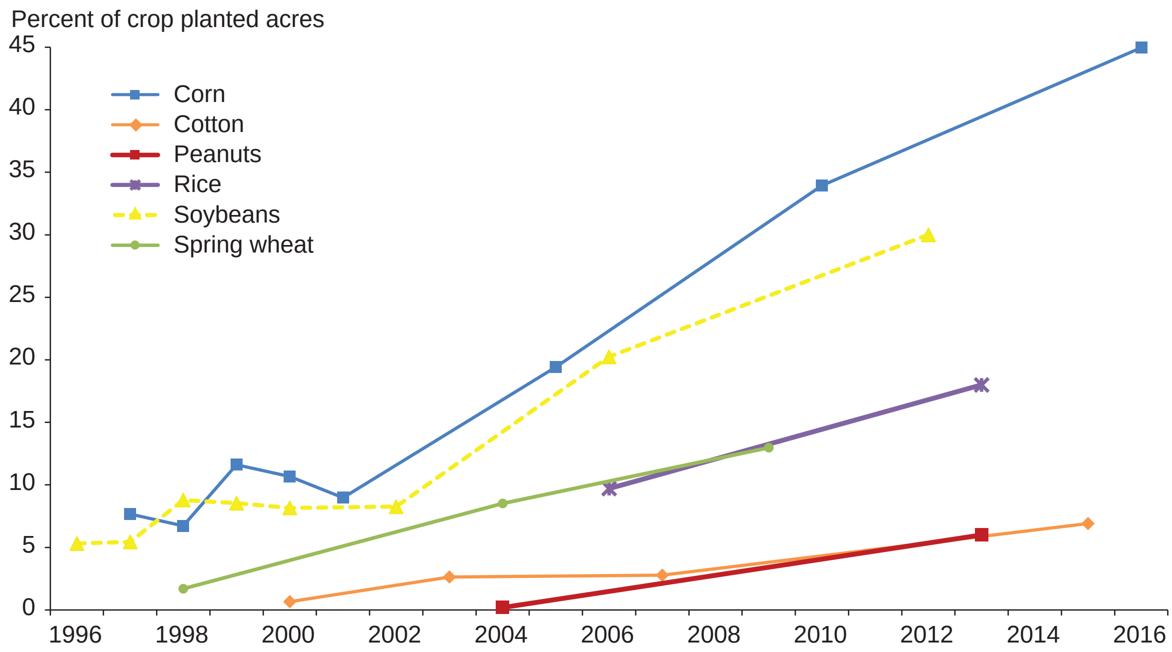



Note: Line markers indicate survey years for each crop.
Source: USDA, Economic Research Service (ERS) estimates using data from ERS and USDA, National Agricultural Statistics Service, Agricultural Resource Management Survey, Phase II.

GPS yield maps synthesize GPS coordinates from yield monitors mounted on combines. Operators can use these maps of crop yields to identify where higher and lower levels of inputs should be applied. Yield monitor data are dense, showing foot-by-foot differences in crop yields in a field during harvest, which can vary greatly year to year depending on rainfall and the specific mix of production practices used. Even with difficulties in interpretation caused by this annual variability,[1] GPS yield mapping was used on 30-45 percent of planted acres for corn and soybeans (2012-16). The use of yield maps for cotton, peanuts, rice, and spring wheat is less common, but also has increased (fig. 2.11.2).

Figure 2.11.2

**Adoption of yield mapping by crop, 1996-2016**



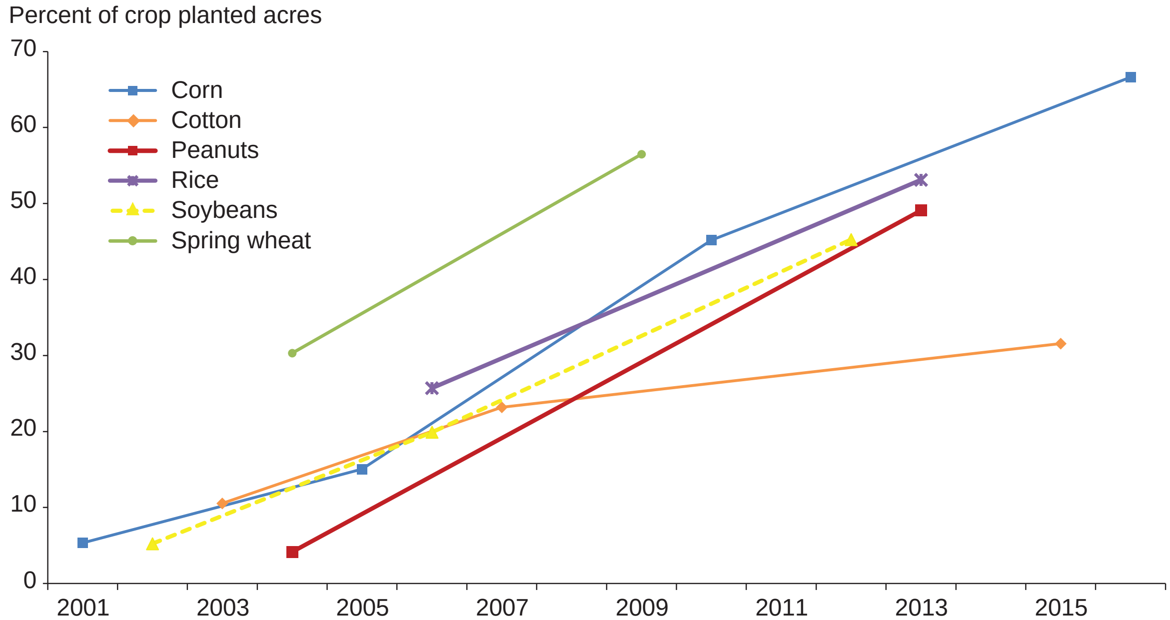

Note: Line markers indicate survey years for each crop.
Source: USDA, Economic Research Service (ERS) estimates using data from ERS and USDA, National Agricultural Statistics Service, Agricultural Resource Management Survey, Phase II.

Soil maps are created from laboratory tests on soil core samples. Although analyzing soil cores can be expensive, even with samples only taken every 20-50 feet in a field, soil cores do provide detailed information on soil characteristics and micronutrient levels. These data are typically used to create zones showing soil types, soil nitrate levels, and pH acidity readings. Like yield maps, farmers use GPS coordinates to georeference points on a field; unlike yield maps, soil characteristics are relatively stable year to year. Thus, zones on soil maps showing soil and micronutrient levels are easier to use (to interpret yields) than yield maps, which are strongly influenced by weather conditions. GPS soil mapping was used on around 20 percent of corn, soybean, and peanut planted acres (2012-16), 15 percent of rice (2013), and 10 percent of spring wheat planted acres (2009) (no figure is shown for these percentages).

[1] Yields can vary a lot within one field location from year to year. To account for this randomness, current recommendations are to use 5-6 years of yield maps to draw conclusions about application rates and other practices.

Guidance systems steer tractors and combines automatically, which helps reduce operator fatigue and pinpoint precise field locations. Guidance systems reduce costs by improving the accuracy of spray applications and the seeding of field-crop rows. The ends of rows, in particular, benefit from more accurate application of inputs. Manually turning farm machinery around to return in the opposite direction in adjacent sets of rows on a field can cause overlaps and missed spots for applied inputs. Guidance systems can also help extend working hours during time-sensitive production periods during the crop year because guided machinery works well in the floodlit dark. Guidance systems had the highest adoption rate of all precision agriculture technologies—used on between 45 and 65 percent of planted acres for corn, peanuts, rice, and soybeans (2012-16), and over 55 percent of planted acres for spring wheat (2009) (fig. 2.11.3).

Figure 2.11.3
**Adoption of guidance systems by crop, 2001-16**




Note: Line markers indicate survey years for each crop.
Source: USDA, Economic Research Service (ERS) estimates using data from ERS and USDA, National Agricultural Statistics Service, Agricultural Resource Management Survey, Phase II.

Outfitting equipment with VRT is expensive, but Schimmelpfennig (2016) shows that VRT improves average profits. In 2010, corn acres using VRT saw a 1-percent increase in profits. About a fifth of planted acres for several crops (figure 2.11.1), such as soybeans and rice, used VRT in 2012-13. Perhaps more surprising is that VRT's supporting technologies—such as GPS mapping, soil mapping, and auto-steer guidance systems—are also profitable on their own. Mapping and auto-steering, for example, added between 2 and 3 percent to corn farm profits in 2010.

The use of these precision technologies is associated with improved onfarm stewardship. Conservation tillage improves soil structure and organic matter (chapter 2.12, "Crop Production Management: Tillage Practices" and chapter 3.19, "Soil Health"). In soybean production, precision agriculture users are about 10 percent more likely than nonusers to practice conservation tillage for all three precision technologies examined (table 2.11.1); 55 percent of U.S. soybean farms use some form of conservation tillage.

Erosion control refers to structures erected for grade stabilization, as well as water-control basins, filter strips, field borders, and contour farming/strip cropping. These practices are used on about one-third of all soybean farms, with 5-8 percent more precision agriculture users than nonusers practicing erosion control; guidance users are the most likely to practice erosion control (relative to nonusers of guidance).

Fertilizer is applied to benefit production, but when fertilizer is overapplied it can degrade water resources through runoff and groundwater contamination. Farmers indicated in their ARMS survey responses if they had changed any of their cropping practices to reduce their use of fertilizer or applied nutrients on soybean fields (2012) (most commonly potassium, phosphorus, or lime, as soybeans are nitrogen-fixing) or changed the type of fertilizer used on rice paddies (2013) to reduce fertilizer use. Almost one-quarter of both soybean and rice farmers indicated that they had changed practices to reduce fertilizer use, and a statistically higher number of these farmers used precision agriculture than did not (table 2.11.1).

Variable-rate technology (VRT) provides interesting crop comparisons. When VRT was adopted on soybean farms, the share of farms that reduced fertilizer use increased by 17 percent (from 21 to 38 percent). This suggests that soybean farmers use VRT as a way to reduce fertilizer use. For rice farms that reduced fertilizer, on the other hand, the difference between the share of VRT users and nonusers is only 2 percent. Overall, VRT use in rice has climbed to over 20 percent, suggesting that many rice farmers use VRT to increase the accuracy of fertilizer placement without reducing their overall use of fertilizer. This means that VRT may not help reduce fertilizer use in all cases but, in some circumstances, fertilizer savings with VRT can be substantial.[2]

Table 2.11.1

**Best management practices on soybeans and rice, by precision agriculture technology, 2012-13**

| | | Percent of farms using practice, by precision technology | | | | | |
|---|---|---|---|---|---|---|---|
| | | GPS soil/Yield mapping | | Guidance system | | Variable-rate technology | |
| Crop and practice | Percent of all farms | Yes | No | Yes | No | Yes | No |
| **Soybeans (2012): soil care** | | | | | | | |
| Conservation tillage | 55 | 61* | 53 | 63** | 51 | 62** | 53 |
| Erosion control | 36 | 40* | 34 | 41* | 33 | 40* | 35 |
| **Reduced fertilizer use** | | | | | | | |
| Rice (2013) | 23 | 28** | 22 | 27** | 19 | 25 | 23 |
| Soybeans (2012) | 24 | 31* | 22 | 29* | 22 | 38** | 21 |

Note: Asterisks reflect 98- and 90-percent confidence (** and *, respectively) in a significant difference between precision technology adopters (Yes) and nonadopters (No) in the use of conservation tillage, erosion control practices, and reduced fertilizer.
GPS = Global Positioning System.
Source: USDA Economic Research Service (ERS) estimates using data from ERS and USDA, National Agricultural Statistics Service, Agricultural Resource Management Survey, Phase II.

[2]While other chemicals can be applied using the VRT method, fertilizer is typically the most important from a cost and yield impact perspective. Rice is an exception, where nonfertilizer chemicals applications using VRT have bigger payoffs.

Several factors are likely to influence the effectiveness of precision technologies in the future. Wireless sensor technologies for crop plants or soil are likely to increase the volume of data on growing conditions available to farmers. Internet-enabled devices can collect sensor data and make crop practice recommendations in real time in a farmer's fields. These developing technologies are likely to be combined with programming known as artificial intelligence (AI), or application equipment may be built with machine-learning capability that can supply more sophisticated recommendations to farmers. These AI and machine-learning innovations can combine data that are growing more plentiful in new ways to produce novel insights on crop-practice effectiveness. This evolution of data availability and data use is going on while farmers are developing more data-driven relationships with trusted advisors and agricultural input retailers, who may use these data resources to help farmers come closer to fully exploiting their data.

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# Chapter 2.12—Crop Production Management: Tillage Practices

Tara Wade and Roger Claassen

- Conservation tillage is used widely on major crops, including 70 percent of soybeans (2012), 40 percent of cotton (2015), 65 percent of corn (2016), and 67 percent of wheat (2017).
- No-till (a form of conservation tillage) varies widely across crops, including 40 percent of soybeans (2012), 18 percent of cotton (2015), 27 percent of corn (2016), and 45 percent of wheat (2017).
- Farms that alternate no-till/strip-till with full-width tillage include roughly 30 percent of all corn, soybean, cotton, and wheat acreage

Reducing or eliminating tillage can reduce soil erosion, conserve soil moisture, and promote better soil health by minimizing soil disturbance and keeping crop residues on the soil surface (Bowman et al., 2016; see also chapter 3.19, "Soil Health" ). Conservation tillage encompasses a range of tillage practices. In a no-till system, farmers plant directly into the undisturbed soil with the residue of the previous crop still on the soil surface. In a mulch-till system, the soil is tilled lightly but much of the previous crop residue is maintained on the soil surface. In a strip-till system soil disturbance is limited by tilling only narrow strips where seeds are planted, also providing an opportunity to place fertilizer below the soil surface.

No-till is more efficient than mulch-till in terms of soil health, soil moisture conservation, and soil erosion control because it causes less soil disturbance and maintains greater soil residue cover. When compared to mulch-till, no-till can also mitigate sediment and nutrient loading in bodies of water and preserve soil depth and productivity (Rittenburg et al., 2015). Limiting soil disturbance and maintaining residue can also increase soil carbon sequestration and improve soil properties in a number of ways, including increased water holding capacity, higher soil organic matter content, and reduced soil compaction (USDA, NRCS, 1996). Evidence also suggests, however, that long-term gains in soil health can be achieved only through consistent application of a suite of practices that includes minimal tillage and practices that increase (1) residue cover and (2) the portion of the year soil is covered by a growing crop (using cover crops, for example) (USDA, NRCS, 2014).

Conservation practices are often part of conservation plans required for highly erodible cropland to maintain eligibility for most Federal agricultural programs. Climate and weather may also play a role in the tillage decision; farmers may use no-till or strip-till to conserve soil moisture in dryer regions or when soil moisture reserves are low, but use other tillage systems when soil moisture is ample (Ding et al., 2009) or in relatively cold conditions (Soule et al., 2000).

## Tillage Practices Vary by Crop

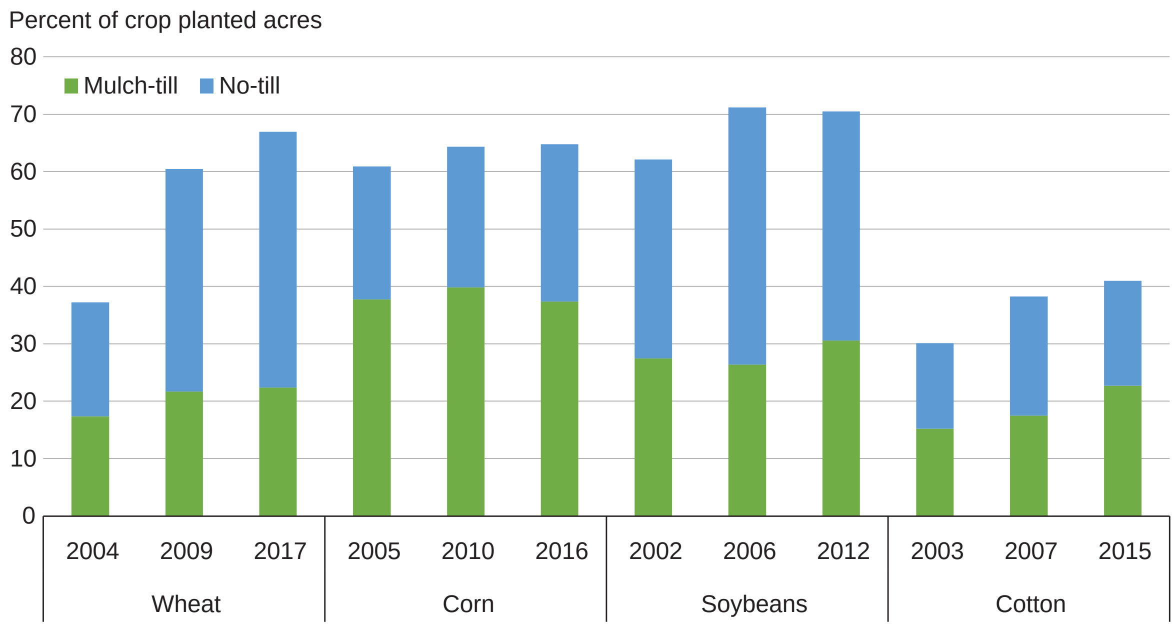
In the field-level portion of USDA's Agricultural Resource Management Survey (ARMS), producers of specific crops are surveyed on a multiyear cycle (e.g., corn producers were surveyed in 2005, 2010, and 2016) to generate a wide range of information on crop production practices. Tillage estimates are based on the sequence of field operations as reported by respondents. Tillage practices can be defined by

the level of soil disturbance. Conservation tillage ranges from no-till to a maximum level of soil disturbance—a Soil Tillage Intensity Rating (STIR) of 80 (USDA, NRCS, 2016).[1]

In general, no-till increased from 2000 to 2007 (Horowitz et al., 2010). More recent data show that trends in no-till adoption are mixed. Over 2004-17, wheat producers increased the share of planted acres under mulch-till or no-till from 37 percent to 67 percent (fig. 2.12.1). No-till accounted for a large majority of the increase. More modest changes in conservation tillage were observed for corn, soybeans, and cotton. For cotton and corn, no-till adoption rates showed only modest gains in the most recent surveys (2015 and 2016, respectively). In soybeans, no-till adoption declined between the two most recent surveys (2006 and 2012). For corn, mulch-till adoption has also been fairly constant from 2005 to 2016. For soybeans and cotton, mulch-till adoption rates have increased slightly.

Figure 2.12.1

**Conservation tillage trends on wheat, corn, soybean, and cotton acres**




Source: USDA, Economic Research Service and USDA, National Agricultural Statistics Service, Agricultural Resource Management Survey, 2002-17.

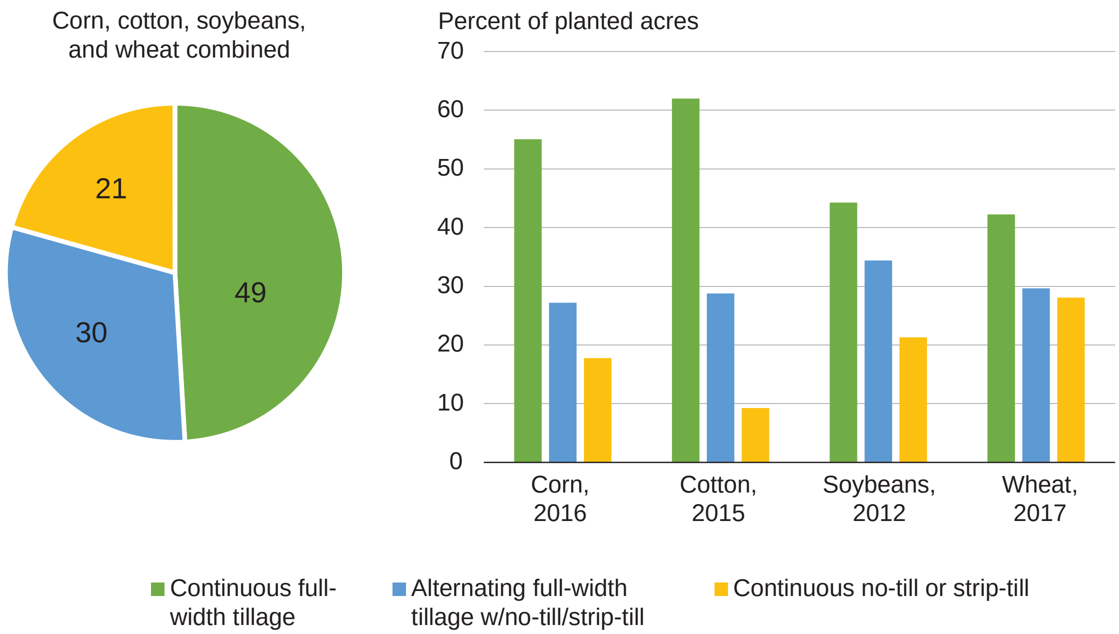
The field-level ARMS data for wheat (in 2017), soybeans (in 2012), cotton (in 2015), and corn (in 2016) provide a 4-year history of no-till/strip-till use.[2] Farmers were asked about no-till use in the survey year and the 3 previous years (although the surveys are crop-specific, any crop could have been grown on the surveyed field in the 3 previous years). Despite the benefits of no-till/strip-till, other tillage practices were used on roughly 80 percent of acres in corn, soybeans, wheat, and cotton at least once during a 4-year period (fig. 2.12.2). No-till was used exclusively for 4 years on 21 percent of soybean acres (2012) and 28 percent of wheat acres (2017). No-till or strip-till was used exclusively on 18 percent of corn acres (2016) and 9 percent of cotton acres (2015).

[1]There is no universally recognized STIR value that defines the upper boundary of soil disturbance consistent with conservation tillage. The national conservation practice standard (USDA-NRCS, 2016) indicates a maximum STIR rating of 80. In actually implementing conservation programs, however, STIR ratings as low as 60 are used to define the upper bound of conservation tillage in some States.

[2]The 2017 wheat and 2012 soybean survey asked only about no-till. The 2015 cotton and 2016 corn surveys asked whether no-till or strip-till was used.

Figure 2.12.2

**Half of fields are tilled each year, 2012-2017**




Note: "No-till" means planting without tilling since the previous harvest. "Strip-till" means tilling only a narrow strip over the row (used only in row crops). "Full-width" tillage is tilling the entire soil surface. For each survey, respondents are asked whether no-till or strip-till was used in each year over a 4-year period. For example, "continuous" no-till or strip-till means that no-till or strip-till was used in each year of the 4-year period.

Source: USDA, Economic Research Service and USDA, National Agricultural Statistics Service, Agricultural Resource Management Survey, 2012, 2015, 2016, and 2017.

## Many Farmers Use No-Till or Strip-Till on a Portion of Their Cropland

Many farmers who use no-till use it on only a portion of their crop acreage. For example, farmers often rotate tillage practices along with crops (Robertson et al., 2014), using no-till/strip-till on crops that are thought to be well suited for the practices (e.g., soybeans) and conventional or mulch tillage for crops where no-till/strip-till are perceived to be more risky (e.g., corn) (Reimer et al., 2012). Some farmers may also select their tillage practice based on field characteristics. For example, farmers may use no-till/strip-till on highly erodible land to control soil erosion and use conventional tillage on land that is not highly erodible (Prokopy et al., 2008).

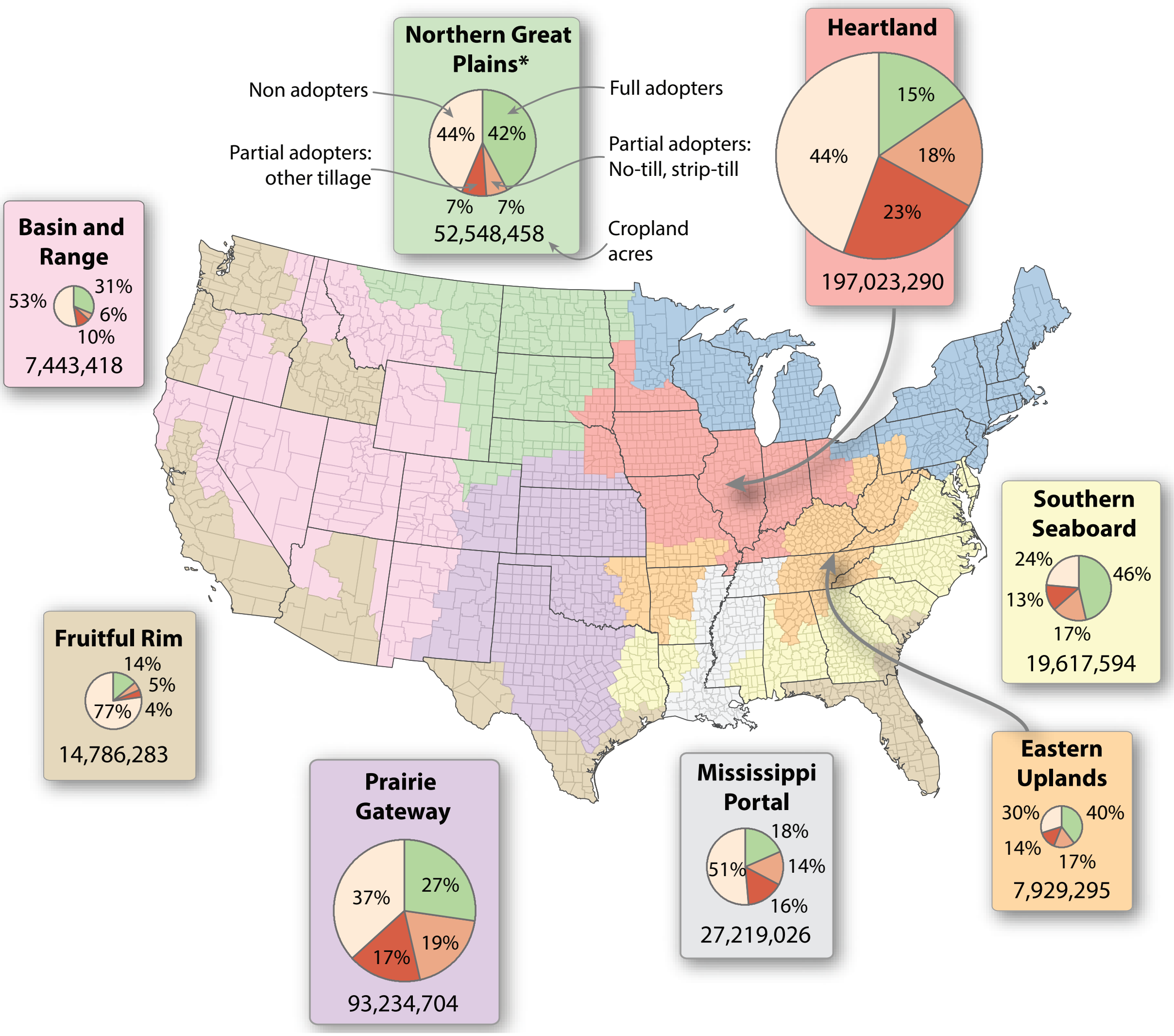
ARMS data for 2010-11 provide a detailed, farmwide look at how farmers used no-till/strip-till on the four most widely grown crops. During those years, 56 percent of all land used for corn, soybeans, wheat, and cotton was on farms that used no-till/strip-till on some portion of land used for these crops. Roughly 23 percent of land in these crops were on a farm where no-till/ strip-till was used on every acre (full adopters). Another 33 percent of acreage was on farms where a mix of no-till, strip-till, and other tillage practices were used (partial adopters). Partial adopters used no-till/strip-till on roughly half of their crop-land (15 percent of land in the four major crops).

Intensity of use among partial adopters varies regionally (fig. 2.12.3). Partial adopters in the Heartland, Prairie Gateway, Eastern Uplands, and Southern Seaboard used no-till/strip-till on 16-20 percent of acres in 2010-11. In the Northern Great Plains, Heartland, and Prairie Gateway regions—which account for 72 percent of U.S. corn, soybean, wheat, and cotton acreage—more than half of these crop acres were on

farms that used no-till/strip-till to some extent. Farmers who use no-till/strip-till on a part of a particular crop acreage have the equipment and expertise (at least for some crops) to use no-till/strip-till but choose to till other portions of their cropland. These farmers may be well positioned to use these practices on a larger share of acres if/when it is advantageous to do so.

Figure 2.12.3

**No-till/strip-till use varies by region, 2010-11**



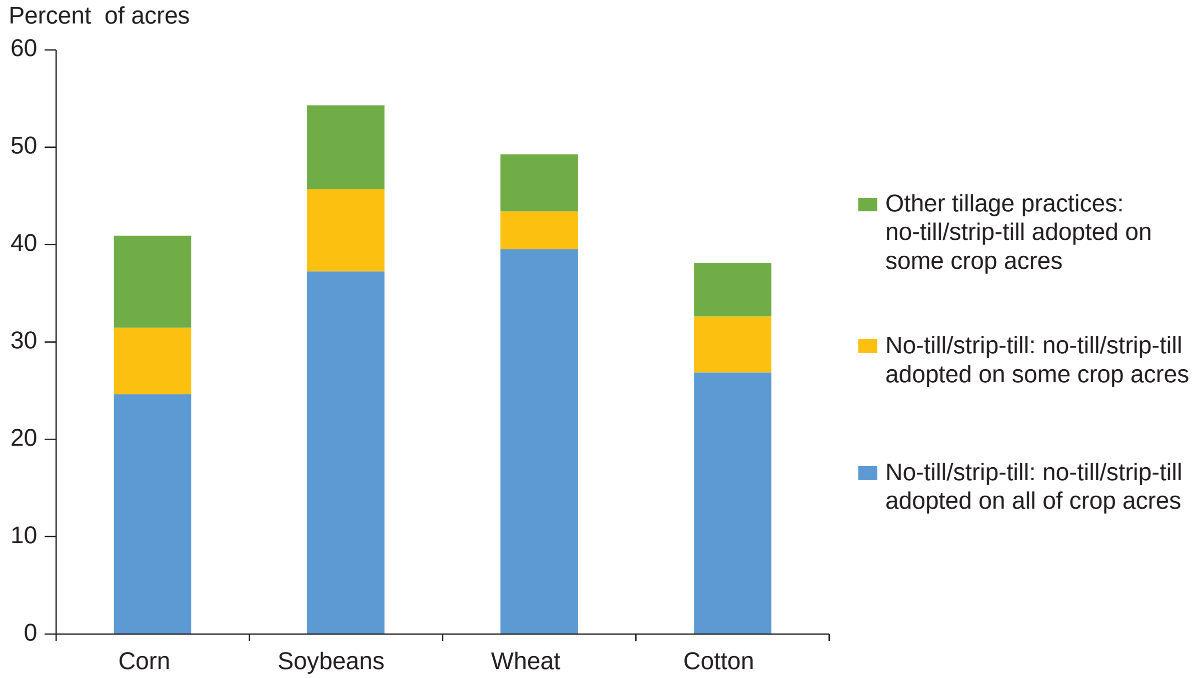

*Estimates for the Northern Crescent (46,783,555 acres) are omitted due to the unreliability of the statistics. The most recent estimates of whole-farm tillage are from the 2010-11 ARMS (its phase III component).

Source: USDA, Economic Research Service and National Agricultural Statistics Service, Agricultural Resource Management Survey (ARMS), 2010-11.

It is not uncommon for farmers who use no-till/strip-till to do so on all their acreage for an individual crop (fig. 2.12.4). About 25 percent of corn acres, 27 percent of cotton acres, 37 percent of soybean acres, and 39 percent of wheat acres (2010-11) occurred on farms that used no-till/strip-till on all the acres in those crops. However, full adoption for one crop does not mean that the farmer will apply that practice to other crops. Only 23 percent of acres in all four crops were located on farms that adopted no-till/strip-till on 100 percent of their acres. That farmers use no-till/strip-till on all acres of a *particular* crop is consistent with the notion that tillage choice and crop choice are closely tied.

Figure 2.12.4

**Farmers adopt no-till/strip-till on part of their farms, 2010-11**[1]




[1]The fourth category (not shown) is other tillage practices on nonadopter farms. The most recent estimates of whole-farm tillage are from the 2010-11 ARMS (its phase III component).
Source: USDA, Economic Research Service and National Agricultural Statistics Service, Agricultural Resource Management Survey, 2010-11.

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# Chapter 2.13—U.S. Organic Farming Systems

Catherine Greene, Claudia Hitaj, and William McBride

- The number of certified organic operations in the United States has more than doubled between 2006 and 2016 in response to rising consumer demand. U.S. organic retail sales are estimated to have reached $49 billion in 2017.
- In 2015, the most recent year with comprehensive USDA estimates, organic farming systems were used on nearly 10 percent of U.S. acres for vegetables, but were used on under 0.3 percent of U.S. corn and soybean acreage.
- Many of the practices associated with soil health—including longer crop rotations, nonchemical pest management, and cover crops—are much more widely used in organic farming systems than in conventional systems.

The long history and comprehensive standards associated with the organic food label, along with its widespread use worldwide, distinguishes organic labels from other eco-labels that have emerged in recent years. In 2000, USDA published national organic standards that reflected decades of private-sector development. USDA's national regulatory program is designed to facilitate interstate trade, reduce fraudulent product claims, and provide consumer assurance that all organic products sold in the United States meet a high national standard. All growers, processors, and distributors that want to label or advertise their products as organic must meet the national standard and must also be certified by a USDA-accredited State or private group unless their annual organic sales are under $5,000.

USDA regulations define organic farming as an ecological production system that fosters resource cycling, promotes ecological balance, and conserves biodiversity. Organic farmers are required to avoid most synthetic chemicals and must adopt practices that maintain or improve soil conditions and minimize erosion. Organic production systems can be used to increase farm income, as well as reduce pesticide residues in water and food, reduce nutrient pollution, improve soil tilth and organic matter, lower energy use, reduce greenhouse emissions, and enhance biodiversity (Reganold and Wachter, 2016; Delate, 2015; Baranski et al., 2014).

## Consumer Demand Drives Adoption of Organic Systems

Organic products have shifted from a lifestyle choice for a small segment of consumers to a commonplace interest for many consumers. In 2014, Gallup included questions on organics in its annual food consumption survey for the first time and found that 45 percent of Americans actively tried to include organic foods in their diets, with an even higher share of younger survey respondents (ages 18 to 29) reporting that they actively try to include organic foods. The share of Americans with annual household income under $30,000 that actively tried to include organic foods was 42 percent, similar to the share for households with incomes of $30,000 to $74,999 (45 percent) and households with incomes over $75,000 (49 percent).

Organic retail sales have shown double-digit growth during most years since USDA set national organic standards and continue to grow rapidly. The Organic Trade Association estimated U.S. organic retail sales at $49.4 billion in 2017, up 6.4 percent from the previous year. While organically grown fresh produce is still the top organic category in terms of U.S. retail sales, U.S. organic milk products have higher price premiums and market share. According to a recent ERS analysis, the highest organic market share in 2014

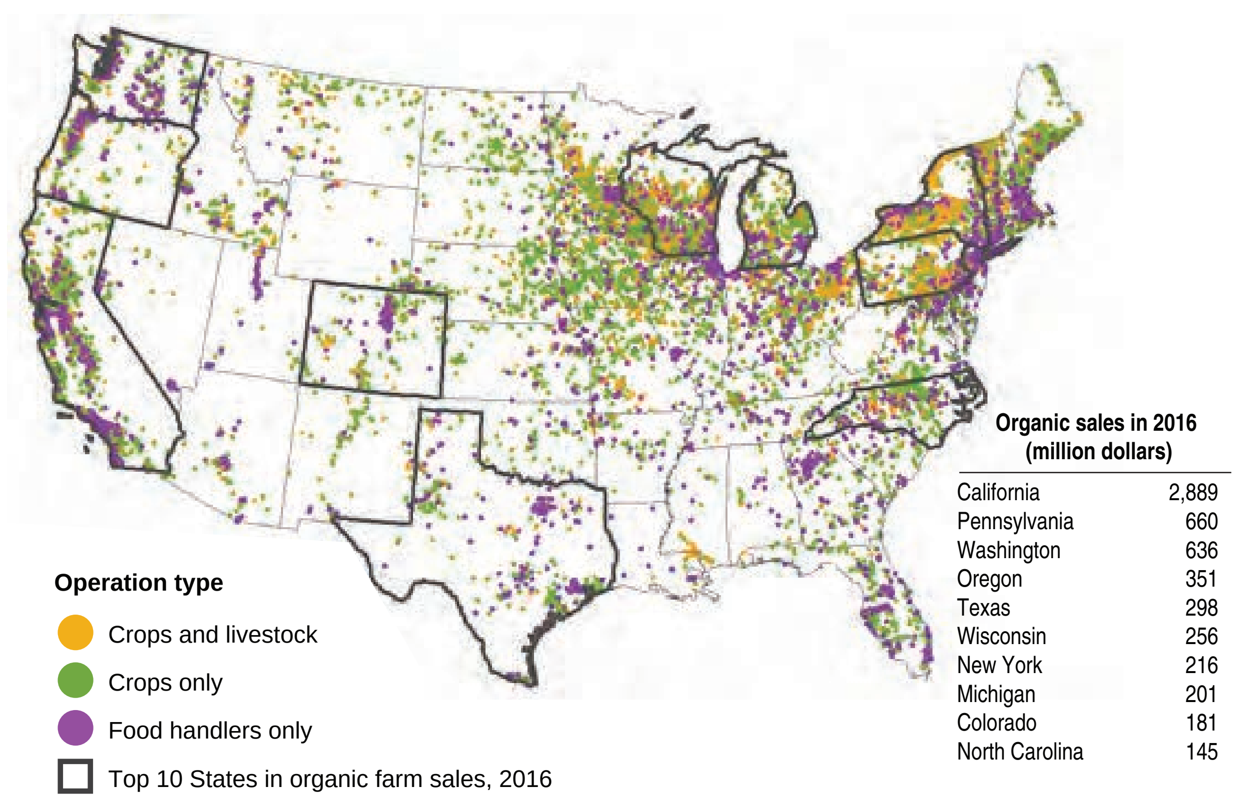
was for organic milk (14 percent of total sales), followed by organic eggs and organic vegetables (both at nearly 7 percent), and organic fruit (nearly 6 percent) (Greene et al., 2017).

In 2015, the United States had 3.2 million acres of certified organic cropland and 2.2 million acres of certified organic pasture (including rangeland). While that land accounted for less than 1 percent of all U.S. farmland, the organic adoption rates varied widely across crop and livestock sectors. For example, organic farming systems were used on nearly 10 percent of U.S. vegetable acres in 2015, but less than 0.3 percent of acres devoted to major U.S. feed grains (corn and soybeans); the share of U.S. dairy and poultry production managed under organic systems falls in between.

The number of certified organic operations in the United States has more than doubled over the last decade in response to rising consumer demand. The United States had over 21,700 certified organic operations in 2015—60 percent were crop and livestock farmers, while 40 percent were processors, manufacturers, and other food handling operators. USDA's organic regulatory program data show that organic farm production and food-handling operations are concentrated in California (the country's top fruit and vegetable producer), the Northeast (which has many small-scale organic farms), and the Upper Midwest (a major producer of organic milk) (fig. 2.13.1). Northeastern States have the highest share of certified organic farmers, particularly Vermont and Maine, where 5 and 6 percent, respectively, of all farmers are certified organic. In California, more than 3.6 percent of all farmers are certified organic (Greene et al., 2017).

Figure 2.13.1

**Certified organic operations are concentrated in the West, Northeast, and Upper Midwest**




| Organic sales in 2016 (million dollars) | |
|---|---|
| California | 2,889 |
| Pennsylvania | 660 |
| Washington | 636 |
| Oregon | 351 |
| Texas | 298 |
| Wisconsin | 256 |
| New York | 216 |
| Michigan | 201 |
| Colorado | 181 |
| North Carolina | 145 |

Note: The category "Food handlers only" includes food processors, manufacturers, and other handlers.
Source: USDA, Economic Research Service using data from USDA's National Organic Program, Organic Integrity Database (U.S. certified operations in January 2016), and USDA's National Agricultural Statistics Service, 2016 Certified Organic Survey.

## Common Organic Practices Include Complex Rotations, Cover Crops, and Pasture

The ecological approach to farming defined by USDA in the national organic standards affects the entire production system (USDA-AMS, 2000). Farmers who shift to organic farming systems from more chemical-intensive systems must make changes across the spectrum of their production inputs and practices.

Under organic farming systems, the fundamental components and natural processes of ecosystems—such as soil organism activities, nutrient cycling, and species distribution/competition—are used as farm management tools. Organic producers rely on complex rotations, cover crops, biological pest management, and other nonchemical practices. For example, crops are rotated, food and shelter are provided for the predators and parasites of crop pests, crop residues are cycled, and planting/harvesting dates are carefully timed (USDA-NRCS, 2016). Conventional farmers use these practices much less frequently than organic farmers.

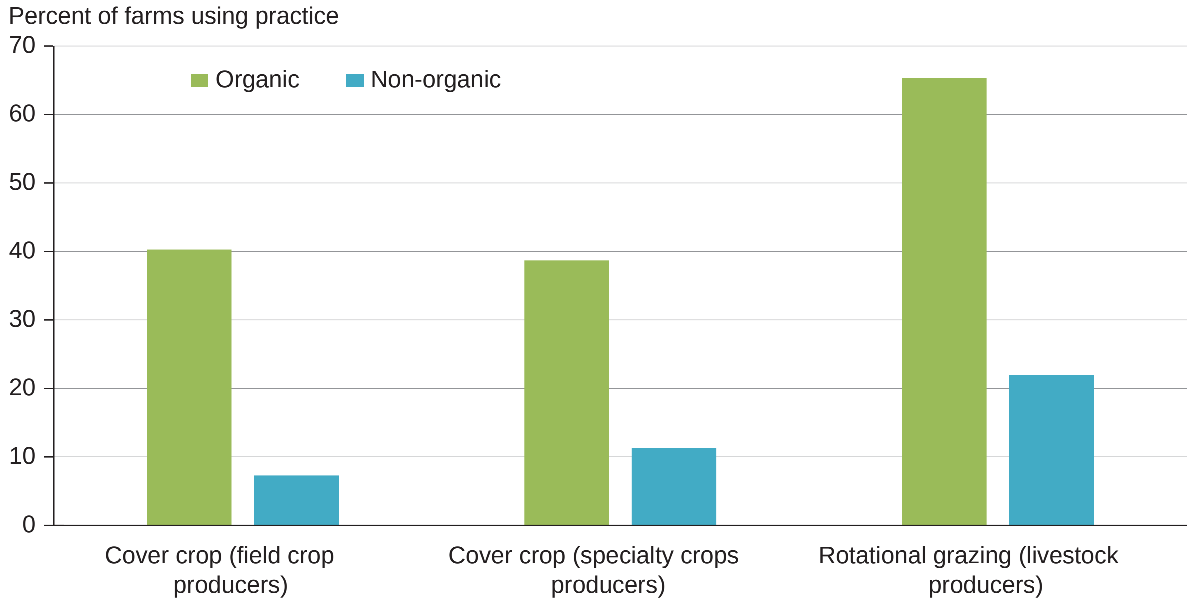
Since the mid-2000s, USDA has surveyed specific organic commodity sectors in the detailed Agricultural Resource Management Survey (ARMS), and also has begun conducting periodic surveys of all organic producers. ERS studies based on data from these surveys confirm that many of the practices associated with soil health are much more widely used in organic farming systems than in conventional systems (see chapter 3.19, "Soil Health"). For example, organic soybean producers often rotate row crops with small grain and meadow crops, and include an idle year in the rotation, while conventional producers mainly use a rotation of continuous row crops (McBride and Greene, 2009). Almost all conventional soybean producers use chemical pesticides for pest and weed control, while organic producers rely on a suite of nonchemical practices. ERS studies show similar patterns for the other field crops.

Other practices that contribute to soil health, soil productivity, and nutrient cycling—including cover crops, animal manure, and compost—are also more widely used in organic farming systems. Data from USDA's national surveys show that nearly 40 percent of all organic field crop and specialty crop producers use cover crops, much higher than among conventional producers (fig. 2.13.2). According to ARMS data, over half of organic apple producers and over 20 percent of organic corn producers use compost, compared with under 3 percent of conventional apple and corn producers (Osteen et al., 2012). Animal manure is also much more widely used in organic field crop production than conventional production.

Tillage is more widely used in organic systems than in conventional systems, and no-till organic systems are still not used commercially in most parts of the country. In a no-till system, farmers plant directly into the undisturbed residue of the previous crop without tillage, except for nutrient injection, which can reduce soil erosion and sediment loss to water and wind. It can also increase soil carbon sequestration (the amount of carbon retained in the soil) and improve the physical, chemical, and biological properties of the soil. Organic no-till systems generally require specialized farm equipment to drill seed into cover crop residues and are more challenging to implement than conventional no-till systems, which rely on chemical herbicides to kill vegetation. Despite heavier use of tillage in organic farming, long-term cropping system experiments at Iowa State University, USDA-Beltsville, Rodale Institute, the University of Minnesota, and others have found that organic cropping systems can sequester as much soil organic carbon, for example, as no-till conventional systems (Delate, 2015).

Figure 2.13.2

**Cover crops and rotational grazing are more widely used by organic producers, 2012-14**




Source: USDA, Economic Research Service using data from 2012 Census of Agriculture (conventional producers) and the 2014 National Organic Producer Survey (certified organic producers).

Organic livestock production systems attempt to accommodate an animal's natural nutritional and behavioral requirements and prohibit the use of antibiotics and hormones in livestock production. USDA organic regulations require that organic dairy cows and other ruminant livestock obtain part of their dry matter intake (forage) from pasture during the grazing season, while many conventional dairy operations did not use any forage from pasture as part of their feeding mix (McBride and Greene, 2009). Rotational grazing—managing where and when livestock graze in order to prevent overgrazing and to optimize pasture growth—is a soil health strategy that is also used more frequently in the organic dairy sector. According to USDA's 2012 Census of Agriculture, 65 percent of organic livestock producers use rotational grazing, compared with 22 percent of conventional livestock producers (fig. 2.13.2).

## USDA Has Expanded Conservation Assistance to Organic Producers

USDA requires a 3-year transition period before conventional farmers can earn organic price premiums, and organic producers also face many challenges after transitioning.  Respondents to USDA's ARMS organic surveys have indicated that weed control, certification paperwork, compliance costs, and input sourcing are among the most difficult aspects of organic production (McBride et al., 2015; McBride and Greene, 2009). Also, U.S. organic producers who grow crops near genetically engineered (GE) crop operations use avoidance practices, such as delaying corn planting until after GE corn is planted, to minimize accidental mixing of organic and GE crops (fig. 2.13.3), which may lower yields from planting at a suboptimal time (Greene et al., 2016).